BALLARD MINE

COVER MATERIAL EXPLORATION WORK PLAN

DRAFT FINAL REVISION 1

Ballard Mine Site

MARCH 2016

Prepared by:

MWH Americas, Inc.

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Prepared by:

MWH AMERICAS, INC.

Prepared for:

P4 PRODUCTION, LLC

TABLE OF CONTENTS

LIST OF DRAWINGS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICIES

LIST OF ACRONYMS

ABA	acid base accounting
ASA	Agronomic Society of America
ASTM	American Society for Testing and Materials
A/T	Agencies and Tribes
bgs	below ground surface
BLM	Bureau of Land Management
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CME	Central Mine Equipment
CO/AOC	Consent Order/ Administrative Order on Consent
COC	chain-of-custody
CWS	center waste shale
DOT	US Department of Transportation
~~DQOs~~	~~data quality objectives~~
ET	evapotranspiration
FWS	Fish and Wildlife Service
GCLL	geosynthetic clay laminate liner
GPS	global positioning system
HASP	Health and Safety Plan
HSA	hollow stem auger
IDEQ	Idaho Department of Environmental Quality
MDD	maximum dry density
OMC	optimum moisture content
P4	P4 Production, LLC
QAPP	Quality Assurance Project Plan
QC	quality control
RA	remedial action
RC	reverse circulation
RD	remedial design
RI/FS	Remedial Investigation/Feasibility Study
SAP	Sampling and Analysis Plan
SOP	standard operating procedure

SPLP	synthetic leachate precipitation procedure
TBD	to be determined
USCS	Unified Soil Classification System
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USFS	United States Forest Service
USGS	United States Geological Survey

1.0 INTRODUCTION

In 2009, P4 Production, L.L.C. (P4) entered an Administrative Settlement Agreement and Order on Consent/Consent Order (2009 CO/AOC; USEPA, 2009a) with the United States Environmental Protection Agency (USEPA); the Idaho Department of Environmental Quality (IDEQ); the United States Department of Agriculture, United States Forest Service (USFS); the United States Department of the Interior including the Bureau of Land Management (BLM) and Fish and Wildlife Service (FWS); and the Shoshone-Bannock Tribes (Tribes), collectively referred to as the Agencies and Tribes or A/Ts. The general objective of the 2009 CO/AOC was to conduct a remedial investigation and feasibility study (RI/FS) of P4's legacy mine sites, the oldest of which is Ballard Mine (the Site). With A/T concurrence, P4 is performing the RI/FS reporting activities sequentially, starting with the Ballard Mine and then moving onto the newer legacy mine sites.

In 2014, P4 completed the remedial investigation for the Ballard Mine, which is summarized in the *Ballard Mine RI Report – Final Revision 2* (*Ballard Mine RI Report;* MWH, 2014). The Ballard Mine FS is being summarized in two memoranda. The *Ballard Mine Feasibility Study Report Memorandum 1 – Site Background and Screening of Technologies* (Ballard FS Memo #1) identifies and evaluates available remedial technologies and the draft was submitted in March 2015. The second technical memorandum (Ballard FS Memo #2) will address the second FS objective by assembling, screening, and comparing a variety of possible remedial alternatives for the affected media at the Site including upland soils/waste rock, surface water, ground water and sediments. This drilling work plan for drilling in the mine impacted area supports the Ballard Mine FS and Remedial Design (RD) process by identifying and characterizing various earthen materials on-Site that can be used as potential cover material and as backfill. In addition, the extent of Meade Peak ore deposits will be further defined. Ultimately, these activities will assist with cut and fill determinations in the RD that will be prepared for the selected Site remedy.

1.1 SCOPE AND PURPOSE

~~The purpose of this drilling work plan is to evaluate the thickness, extent, and geotechnical/ geochemical characteristics of various formations within the Ballard Mine footprint for use as cover materials. This work plan provides details regarding the methods, equipment, and procedures to be used for drilling and sampling during this investigation.~~

One of the objectives of the 2016 drilling program is to define the types and quantity of potential cover material that exists in the mine-disturbed footprint. These data will be collected primarily to assist with the RD, but also if acquired in time, to provide details in the FS including quantities of various On-Site earthen materials. It will be necessary to determine whether these materials have been affected by the existing mine wastes (e.g., because they underlie an existing waste rock dump), or if they are suitable materials to be used as part of a protective cover system (e.g., clean materials). Once this has been determined, the geotechnical properties of these materials will determine their use as summarized below.

- Topsoil and Alluvial Materials – Depending on the geotechnical properties, this could be used as cover material in either an evapotranspiration (ET) or multilayer (e.g., geosynthetic clay laminate liner [GCLL]) cover system.
- Rex Chert Member of the Phosphoria Formation – Chert is often used as a capillary break material in ET covers at other nearby mines because of its durability and permeability characteristics. It can be used for other construction projects such as roads due to its durability.
- Dinwoody Formation – The shale material of the Dinwoody Formation might be used as a component in the cover system (a subsoil storage layer in an ET cap), or as an additional clean layer that is graded to the proper contour prior to application of the final cover system.
- Wells Formation – The Wells Formation limestone has similar uses to the Rex Chert Member, although it has buffering capacity that could be used selectively (e.g., wetlands at the edges of the cover system). Also because of its durability, it might be used as a capillary break layer in a cover system or to line downdrain channels, or to surface Site roads.

If any of these materials are contaminated, they will used as backfill along with the existing waste rock to create the proper slope then covered with a protective cover system.

The number of borings and the locations proposed in this plan allow for the necessary information to be collected. In general, the areas where borings are proposed is where P4 has limited information and Site knowledge. Understanding the alluvium and bedrock characteristics in these locations is important for evaluation of the available on-Site materials for a possible cover system.

Other phosphate mines in the vicinity have a variety of cover systems and are being evaluated. Based on these evaluations, a multilayer and ET cover system will be proposed for the Ballard Site in FS Memo #2 and if possible, the estimated volumes of these materials will be provided. Data collected during the drilling program primarily will be used for further refinement of the Ballard Site cover design during the RD.

A second objective of the 2016 drilling program is further define the extent and thickness of the Meade Peak Formation in portions of the Site. This work plan provides details regarding the methods, equipment, and procedures to be used to fulfill the objectives of this investigation. ~~for drilling and sampling during this investigation.~~

1.2 REPORT ORGANIZATION

The remaining sections of this document include the following:

- Section 2.0 – Discusses the Site setting and geology
- Section 3.0 – Presents the ~~Data Quality~~Program Objectives ~~(DQOs)~~ and investigation approach
- Section 4.0 – Presents the Sampling and Analysis Plan (SAP)
- Section 5.0 – Presents the Quality Assurance Plan (QAPP)
- Section 6.0 – Discusses the Health and Safety requirements (HASP)
- Section 7.0 – References

2.0 BACKGROUND

2.1 SITE SETTING

Ballard Mine is located approximately 13 miles north-northeast of Soda Springs, Idaho in Caribou County (**Drawing 2-1**) and is accessed via the Blackfoot River Road, off of State Highway 34. Ballard Mine was in operation between 1952 and 1969 and is comprised of external mine waste dumps, open pits, an abandoned haul road, and the Ballard Shop Area, all of which cover approximately 534 acres of disturbance. P4 owns approximately 865 acres of surface rights and has a surface easement from the State of Idaho on an additional 360 acres. These properties contain all of Ballard Mine (**Drawing 2-1**). The adjoining properties are all privately held ranching and farming properties. The nearest downstream Federal land is a 40-acre BLM parcel approximately one mile southeast of the mine.

2.2 SURFACE FEATURES

Lands adjacent to the Ballard Mine are agricultural, with grazing to the east and cultivated fields to the west. Natural topography dominates the landscapes adjacent to the Ballard Mine.

Mine Pits and Mine Waste Dumps. The configuration of the mine waste dumps and pits is shown on **Drawing 2-1.** There are six mine pits at the Site. The largest pits are MMP035 (the West Ballard Pit) and MMP036 (Central Ballard Pit) located on the western edge and in the central portion of the Site, respectively. Three smaller pits, MMP037, MMP039 and MMP040 are located in the eastern portion of the Site. The MMP038 pit is a small closed pit located south of the mine features.

There are six mine waste dumps at the Site – MWD080, MWD081, MWD082, MWD083, MWD084, and MWD093. The mine waste dumps at the Site are generally flat topped with angle of repose outer slopes. Waste rock was also placed in mine pits MMP035 and MMP036.

Ancillary Facilities. At this time, the only ancillary facilities remaining at the Ballard Mine are remnants of a partially paved haul road, various unimproved soft surface two-track roads, and the Ballard Shop Area consisting of a large garage/shop building, various small storage sheds and buildings, and a stockpile of slag from the P4 Soda Springs plant. This stockpiled slag is being used for maintenance on haul roads and associated facilities consistent with accepted uses on P4's plant site and other P4 facilities per the 1996 P4 Soda Springs Plant's AOC.

Surface Cover Materials and Vegetation. Based on the 2009 upland soil and vegetation investigation, surficial material on mine waste dumps at the Ballard Mine consists mainly of an approximate 2:1 mixture of weathered brown shale and black shale. The weathered brown shale represents the weathered rock stripped from the near surface during mining to reach the ore beds of the Meade Peak Member of the Phosphoria Formation, and the black shale is typically the waste shale that was located between and immediately above and below the Meade Peak Member ore beds, often referred to as the center waste shale (CWS). Limestone and sandstone typically are found near the base of Wells Formation highwalls. Dolomite or limestone boulders are present primarily near the edges of highwalls and pits.

The vegetative cover is relatively dense in some areas consisting mainly of grass and forbs species and with other areas possessing a higher percentage of woody species. The vegetation at the Ballard Mine is a combination of planted (shrub and trees) and seeded (e.g., alfalfa), along with volunteer vegetation from seeds blown in from the surrounding area.

Several steep slopes, primarily highwalls and angle-of-repose slopes in the southern portion of the Ballard Mine, are unvegetated. Detailed information, on the soil and vegetation surveys conducted in 2009, can be found in Appendix A2 of the *P4 Sites RI/FS Work Plan (*MWH, 2011*).*

2.3 GEOLOGY

The Ballard Site is located nearly on the boundary between the Basin and Range and Rocky Mountain Physiographic Provinces, and the geology in the Ballard Mine area is transitional between these provinces. The geology of the Ballard Site area is characterized by linear, north-south trending, east and west dipping, fault-bounded basins and ranges formed by Basin and Range extensional tectonism. This structural fabric overprints earlier compressional structures that includes major overthrusting, which resulted in synclinal-anticlinal folds and some faulting. **Drawing 2-2** shows the surficial geology at and adjacent to the Ballard Mine.

Ranges in southeast Idaho are generally composed of deformed Paleozoic and Mesozoic sedimentary rocks, including thick marine clastic units, cherts, and limestones. The valleys are largely filled with Quaternary alluvium and colluvium that overlie Pleistocene basalt flows in some places. Massive accumulations of marine sediment occurred over a large area of eastern Idaho, southwestern Montana, and northern Utah during the Paleozoic era. In the Permian, the Phosphoria Formation was deposited creating the western phosphate field which includes the SE

Idaho phosphate resource area. The Phosphoria Formation has four members (from oldest to youngest): the Meade Peak Phosphatic Shale, Rex Chert, Cherty Shale, and Retort Phosphatic Shale. The Meade Peak Member, which ranges in thickness from about 55 to 200 feet, is the source of most of the extracted phosphate ore. This is the oldest member of the Phosphoria Formation and is typically overlain by either the Rex Chert or the Cherty Shale. The Retort Member is discontinuous and is found in the northern and eastern parts of the region, but not in the vicinity of the Ballard Site (USGS and USFS, 1977).

Another significant sedimentary unit, in the area, is the Triassic Dinwoody Formation, which is made up of upper and lower units consisting of limestone, siltstone, and shale. The lower Dinwoody Formation directly overlies the Phosphoria units in the stratigraphic section. The upper and lower units are often separated by a distinct layer of Woodside Shale.

The Meade Peak Member of the Phosphoria Formation is underlain by the upper unit of the Wells Formation, which consists of sandstone interbedded with limestone and dolomite. In some locations, the Grandeur Limestone of the Park City Formation is present above the Wells Formation and is usually considered part of the Wells Formation for mapping purposes.

3.0 EXPLORATION PROGRAM

Additional data are needed to characterize the depth, extent, and geotechnical and geochemical properties of geologic units overlying the Meade Peak Member of the Phosphoria Formation including alluvium, the Dinwoody Formation, and the Rex Chert Member of the Phosphoria Formation within the Ballard Mine. Also, the thickness and extent of the Meade Peak Member of the Phosphoria Formation will be defined in the investigation area. These exploration activities will better define the soil and rock types and the approximate extent and quantities of these materials within the Site. Based on the results of the proposed drilling and testing conducted under this cover materials and exploration program (**see Drawing 2-2**), recommendations for the use of these materials as cover, backfill (e.g., type and characteristics of material availability and estimated volume), or as an incidental source of ore will be utilized during the RD process.

3.1 ~~DATA QUALITY OBJECTIVES~~OBJECTIVES OF THE COVER MATERIAL EVALUATION

The ~~data quality~~ objectives of the investigation are summarized below:

- Characterize the geochemical properties of the Dinwoody Formation and Rex Chert Member of the Phosphoria Formation for use as cover or backfill materials during the RD/remedial action (RA).
- Characterize the geochemical, geotechnical and agronomic properties of alluvium for use as cover materials during the RD/RA.
- Evaluate the thickness of waste rock dumps in some areas of the Site.
- Determine the location and lateral extent of the Meade Peak Member (ore member) of the Phosphoria Formation throughout the Site to aid evaluation of incidental ore recovery during the RD/RA.
- Identify the existence and depth to groundwater in areas that may be encountered during the RD/RA (e.g., during ore recovery and/or during excavation of materials for cover or backfill materials).

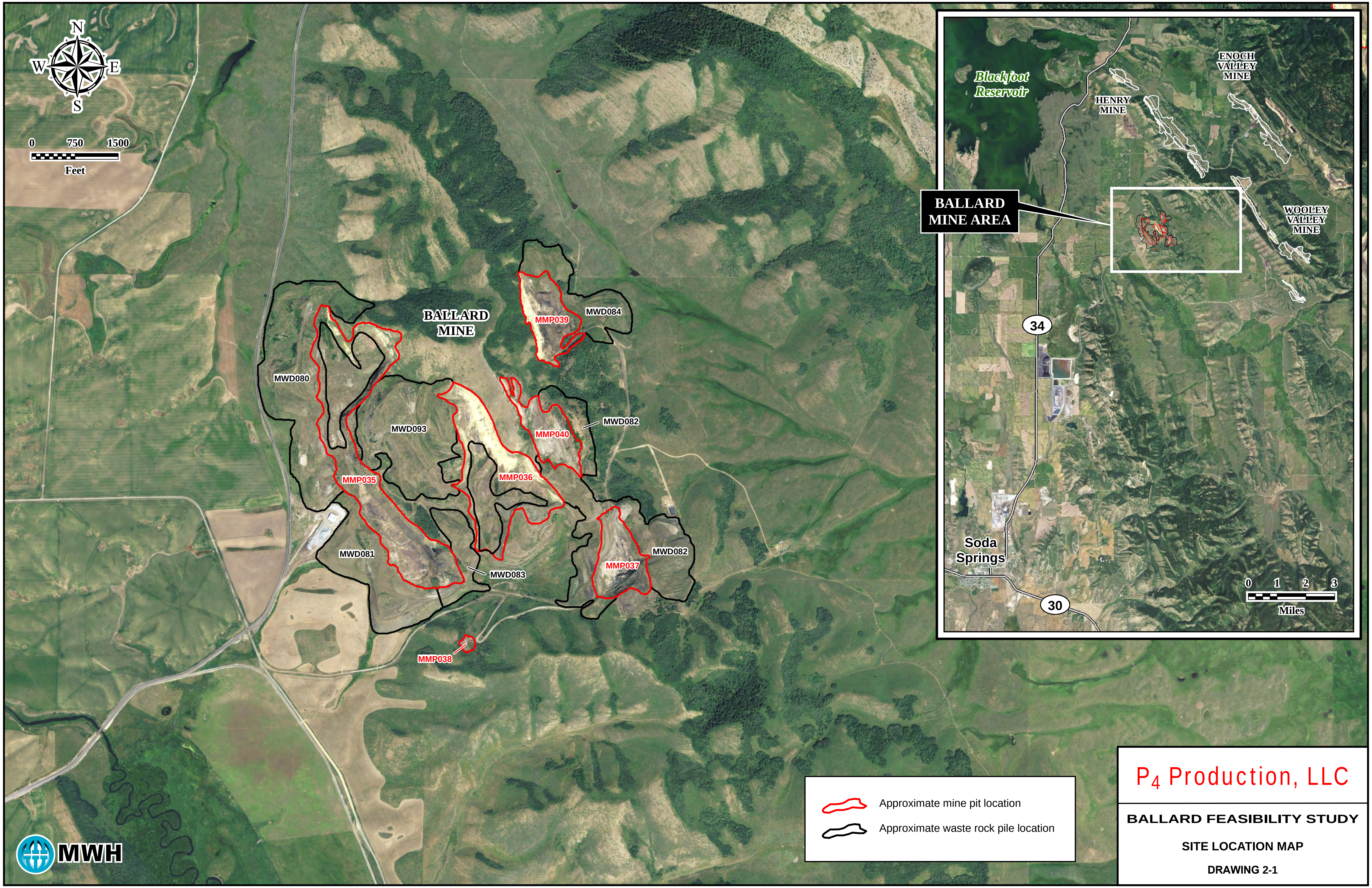
3.2 COVER MATERIAL EVALUATION

The geologic units overlying the Meade Peak Member of the Phosphoria Formation will be evaluated for use as cover ~~or backfill material~~ as described in Section 1.1. The exploration program currently includes an estimated total of 68 borings that will be drilled within the Ballard Mine area using hollow stem auger (HSA) and reverse circulation (RC) drilling methods (see **Drawing 2-2**).

Additional borings or test pits may be added or removed based on field observations. P4 will communicate these changes to USEPA. Samples made up of vertical composites of soil/rock cuttings in ~~each~~ the borings will be collected from the alluvium/colluvium, Dinwoody Formation and Rex Chert Member of the Phosphoria Formation. The geotechnical and geochemical testing performed on samples collected from each boring will vary based on what geologic units are encountered as further detailed in the SAP in Section 4.0.

3.3 ORE BODY EXPLORATION

Currently, ~~53~~50 borings will be drilled using RC drilling methods through the Meade Peak Member of the Phosphoria Formation and into the underlying bedrock. The purpose of these borings is to investigate the thickness and extent of the Meade Peak Member in the mine disturbed area. These proposed exploration borings will be completed in conjunction with the other geotechnical and geochemical drilling of the overburden materials described above. At some locations, two borings (angled and vertical boring) will be drilled from the same pad. The purpose of these borings is to understand the geologic structure and orientation of the Phosphoria Formation in these particular locations. Additional borings may be added or removed based on field observations and these changes will be communicated to the USEPA.



DRAWN BY D. Severson

19 Jan 2016

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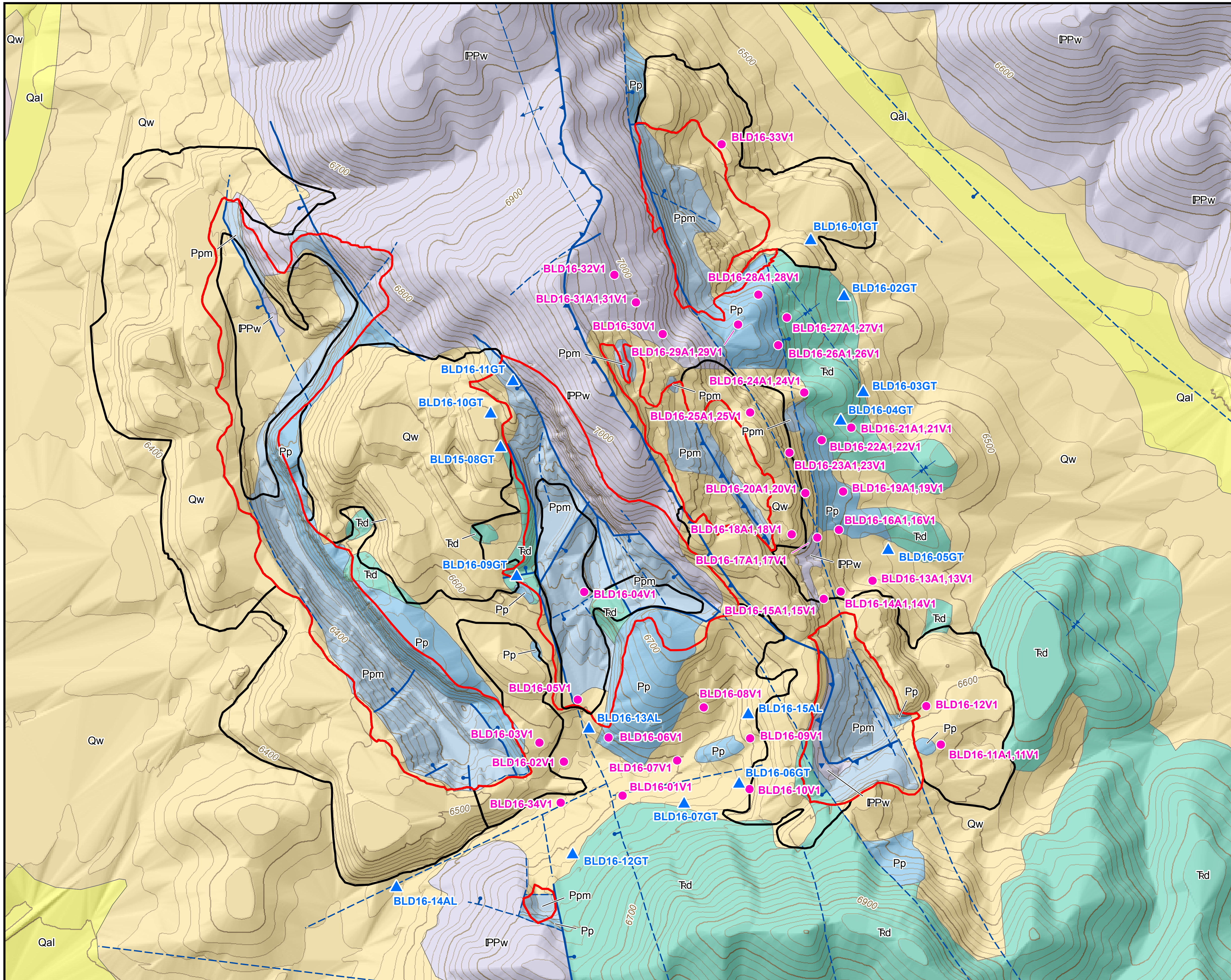

EXPLANATION

- Proposed reverse circulation borehole
- Proposed hollow stem auger borehole
- Qb Basalt
- Qal Alluvium
- Qw Colluvium and older alluvium, may include areas covered in mine waste rock
- Ƭd Dinwoody Formation - Woodside Shale
- Phosphoria Formation
  - Pp Rex Chert and Cherty Shale Members
  - Ppm Meade Peak Member
- IPPw Wells Formation
- Mb Brazer Limestone
- Fault
- Approximate or inferred fault
- Normal fault (ball on downthrown block)
- Thrust fault
- Axis anticline
- Axis syncline
- Approximate mine pit location
- Approximate waste rock pile location

N
W E
S

0 400 800

Feet

CONTOUR INTERVAL 20 FEET

GEOLOGIC DATA SOURCES: Hovland, 1981; Mansfield, 1927

P_4 Production, LLC

BALLARD FEASIBILITY STUDY

GENERALIZED GEOLOGIC MAP SHOWING PROPOSED EXPLORATION BOREHOLES

Drawing 2-2

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19 Jan 2016

D:\MWH\P4 Monsanto\P4_Ballard_FS_Jan2015\FIGURES\Dwg 2-2_Ballard_Gen Geo Map Showing Prop Expl Boreholes_19Jan2016.mxd

4.0 SAMPLING AND ANALYSIS PLAN

This section presents the SAP for the Ballard Mine cover material investigation and ore exploration program. Specifically, this SAP presents a detailed description of the following:

- Number of samples to be collected;
- Type and frequency of testing to be performed; and
- Methods and equipment to be used for sampling and testing.

The proposed investigation boring locations are presented in **Drawing 2-2.** A QAPP for the field sampling and laboratory testing program is presented in Section 5.0. SOPs for soil and rock borings, test pits, and material classification are presented in **Appendix A** as listed below.

- SOP-1 – Soil Boring and Drilling
- SOP-2 – Soil and Rock Classification
- SOP-3 Trenching and Test Pits

4.1 SOIL AND ROCK SAMPLING AND TESTING

4.1.1 Soil/Rock Sampling Protocols

Soil/rock samples will be collected from each proposed boring by P4 or its representative. The current program includes 68 borings that will be drilled within the Ballard Mine cover materials and exploration investigation area (**see Drawing 2-2**). The borings will be drilled using RC and HSA drilling methods depending on the boring depths and sampling objectives. As currently proposed, ~~46~~40 geochemical and ~~10~~ 20 geotechnical soil/rock tests will be collected as composited (i.e., disturbed) samples from drill cuttings or soil cores. Additional soil/rock samples (to be determined [TBD]) may be collected based on findings and observations made in the field. A summary of the geochemical, ~~and~~ geotechnical, and agronomic soil samples and the associated analyses is presented in **Table 4-1**.

Geochemical, geotechnical, and agronomic soil samples obtained from RC drilling methods will be randomly collected and retained over approximately 5 to 10-feet intervals every 20 feet (e.g., 10-20 feet below ground surface [bgs] in the first 20 feet, 30-40 feet bgs in the 20 to 40 feet interval, etc.). Enough sample will be collected to fill one sample bag for geochemical analyses and one, five-gallon bucket of material for geotechnical analyses, if needed. This sampling is further described below in Sections 4.1.2 and 4.1.3.

Geochemical, geotechnical, and agronomic soil samples collected from HSA drilling methods will be collected every five feet using a Central Mine Equipment (CME) sampling system or split spoon sampler. These samples will be collected from soil cores collected over each depth interval (e.g., approximately 5 to 10-feet intervals) by filling two, five-gallon buckets with representative soil/rock. Again, depending on field conditions, additional soil samples may be collected of shallow alluvium or Dinwoody material using test pits.

In the event that groundwater is encountered, the boring will be continuously logged to total depth; however, no samples will be submitted for geochemical or geotechnical analysis from depths below the contact with water.

In general, geochemical samples will be collected from the Rex Chert Member and the Dinwoody Formation, where encountered. Geotechnical samples will be collected from alluvium and possibly from the Dinwoody Formation, where encountered (see **Table 4-1**).

Currently, undisturbed samples are not planned for collection as part of this investigation. However, based on observations in the field, the geotechnical borings and/or soil sample collection protocols may be modified to accommodate undisturbed samples if the P4 Project Manager requests the sampling of undisturbed soil. If undisturbed samples are collected, they will be collected using a thin-walled sampler such as Shelby tube or similar equipment. Upon recovery from the boring, the undisturbed sample will be wrapped in plastic sheeting (e.g., Visqueen) and placed in a cooler to preserve the moisture in the sample.

4.1.2 Geochemical Testing

Geochemical samples will be collected to determine the leaching potential of overburden units that may be used as clean cover materials during the RD/RA. The proposed geochemical testing program is summarized in **Table 4-2**. An estimated ~~thirty-nine~~ten (~~39~~10) samples from the Rex Chert Member~~ and~~, ~~seven~~ twelve (~~7~~12) samples from the Dinwoody Formation will be collected from the vertical RC and HSA borings for geochemical analyses as presented in the **Table 4-1** and summarized at the bottom of the table.

The actual sample location (i.e., depth intervals, type of rock) will be determined in the field based on random selection of one sample from the composite samples that are retained every 20 feet, as described above. At least one sample will be sent for whole rock elemental analysis and acid-base accounting (ABA) for every 100 feet in each geologic unit in every boring indicated in **Table 4-1** (e.g, two Rex Chert samples submitted for analysis when 200 feet of Rex Chert is encountered and one Dinwoody sample submitted for analysis when 40 feet is encountered). Additional samples may be collected based on professional judgment (e.g., subtle changes in lithology within a formation). The rock chip samples will be subjected to the following geochemical testing:

- Whole Rock Elemental Analysis (EPA 3050B/6020/6010) - used to determine constituent concentrations in each lithology.
- ABA (Modified Sobek) - used to identify any potentially acid generating lithologies.
- Synthetic Precipitation Leachate Procedures (SPLP) (EPA 1312/6020/6010) - used to evaluate whether metal constituents of concern have the potential to leach from the materials that may affect water quality.

Based on the results of the whole rock elemental analysis and ABA tests, which will be performed on ~~every~~ Rex Chert and Dinwoody samples submitted to the laboratory, SPLP tests will be run on approximately 30% of the samples. Alluvium samples for SPLP will be selected from the HSA borings or text pits where agronomic/soil chemistry samples are collected. Samples for SPLP analysis will be selected based on the range of whole rock constituent concentrations or alluvial soil concentrations, but will be biased toward those samples that report the highest analyte concentrations.

Table 4-2 - Geochemical Testing Program

Test/Method	Minimum Number of Samples	Comments
• Whole Rock Analysis (EPA SW846 3050B / EPA 6020/6010B ICP/ICP-MS Analysis) As, Cd, Se, and U • Acid-Base Accounting (Modified Sobek)	12 + 2 ~~(~~QC~~)~~ Dinwoody samples **Refer to Table 4-1** ~~39~~ 10 + ~~4~~ 1 ~~(~~QC~~)~~ Rex Chert samples **Refer to Table 4-1**	If alluvium is present, it will be sampled according to **Table 4-3** and **Table 4-4**. For Dinwoody and Rex Chert borehole intervals, vertical composite rock chip samples will be collected at 20-feet intervals for the total depth of each RC or auger borehole (5 samples over 100 feet). After completion of the borehole, for every 100 feet of Dinwoody or Rex Chert, 1 of the 5 composite samples will be randomly selected for whole rock and ABA analysis as described on **Table 4-1**. Additional samples analyzed as needed based on lithologic variations in each stratum.
• Synthetic Precipitation Leaching Procedure – SPLP (EPA 1312 / EPA 6020/6010B ICP/ICP-MS) As, Cd, and Se	~~3~~ 4 + 1 (QC) Dinwoody samples ~~12~~ 3 + ~~2~~ 1 (QC) Rex Chert samples 3+ 1 (QC) Alluvium samples	Based on the range of results from the whole rock/~~-~~ABA analyses or soil agronomic/chemistry analyses, approximately 30% of the ~~whole rock~~ samples at the lab will be selected based on professional judgement for SPLP analysis.

4.1.3 Geotechnical Testing

The geotechnical samples will be collected to determine several physical parameters including hydraulic conductivity and Proctor tests of the representative geologic unit. The proposed geotechnical analytical program is summarized in **Table 4-3**. This investigation will be used to identify and evaluate the geotechnical properties of potential alluvial cover materials overlying bedrock in the disturbed area of the Ballard Mine. Based on actual characteristics, this alluvial material may be used in cover systems during the Ballard Mine remediation. During this investigation, an estimated 10 alluvial samples will be collected for geotechnical analysis as presented in **Table 4-1** and summarized at the bottom of the table. Additional alluvial samples will be collected for analysis based on professional judgement (e.g., whether adequate thickness of alluvium exists due to preparation of the drill pad or changes in soil/rock type).

The program will rely on geotechnical samples collected from either the HSA borings using split-spoon samplers or test pits to the extent possible although alluvial cuttings from the RC borings may be collected and analyzed based on field conditions~~, if an adequate number of alluvial samples from the HSA borings is not obtained.~~ Geotechnical testing for double dispersion and soil water characteristic testing will be completed on approximately 50% of the alluvial samples submitted to the laboratory for analysis.

Samples of the Dinwoody Formation encountered in the HSA borings or test pits may be collected for analysis based on professional judg~~e~~ment (e.g., sample consists of weathered bedrock/soil-like material). It is estimated that up to ~~five~~ 10 Dinwoody Formation samples may be submitted to the laboratory for geotechnical analyses.

At least one randomly selected composite sample of each material type will be collected from each of the HSA borings listed in **Table 4-1**. The actual sample location (i.e., depth intervals, type of soil/rock matrix) and number of samples submitted will be determined in the field. The composite soil samples will be subjected to the following geotechnical testing:

- Organic Content (American Society for Testing and Materials (ASTM) D2974) - used to determine the moisture content, ash content and percent organic matter in soil;
- Atterberg Limits (ASTM D4318) - used to evaluate the shrink-swell potential of the soil and its propensity to develop desiccation cracks during cyclical wetting and drying;
- Unified Soil Classification (ASTM D2487) and Grain Size Distribution Bulk (ASTM D422) - used to determine particle size distribution and as an indicator of material properties across the entire borrow area. Generally, soils having the same or similar particle size distribution will have similar physical properties;
- Specific Gravity (ASTM D854) – this test is used to determine the specific gravity of soil solids passing a sieve by means of a water pycnometer;
- Hydrometer Analysis (ASTM D422), Double Dispersion (ASTM D4221) and Crumb Test (ASTM D6572-12~~D4221~~) - used to evaluate the erosive potential of the soil due to dispersion;
- Standard Proctor (ASTM D698) – used to further refine the maximum dry density (MDD) and optimum moisture content (OMC) of the soil for specifying the percent compaction and in-place density of the soil;
- Permeability Falling Head (ASTM D5084) – used to determine the hydraulic conductivity of saturated porous soil material; and

- Soil Water Characteristic Testing – 8 point (ASTM D6836) – used to determine the hydrological characteristics of unsaturated soil.

Table 4-3 – Geotechnical Testing Program

Test/Method	Minimum Number of Samples	Comments
• Organic Content (ASTM ~~D2937~~D2974) • Atterberg Limits (ASTM D4318) • USCS Classification (ASTM D2487~~D4318~~) • Specific Gravity (ASTM D854) • Grain Size Distribution Bulk (1-gallon) (ASTM ~~D433~~D422) • Hydrometer (ASTM D422) • Standard Proctor (ASTM D698) • Crumb Test (D6572-12) • Permeability; Falling Head (ASTM D5084)	10 alluvium samples Refer to **Table 4-1** TBD Dinwoody samples	Vertical composite samples will be collected from split-spoon samplers at approx. 5 -feet intervals (1-2, 5-gal buckets*) for the total depth of each HSA borehole. Alluvial cuttings will be collected from the RC boreholes (1-2, 5-gal buckets*), as needed. Additional samples may be collected from test pits. 1 composite alluvial sample will be randomly selected for geotechnical analyses from borings listed in **Table 4-1**. Additional alluvial samples analyzed based on lithologic variations in each stratum. Dinwoody samples analyzed based on weathered nature of the bedrock. *Collect 2, 5-gal buckets of material for coarse-grained samples (>25% of ¾" material)
• Soil Water Characteristic Testing (8 points) Double Dispersion (ASTM D4221)	5 alluvium samples	50% of the geotechnical samples will be randomly selected and analyzed for additional geotechnical tests.

4.1.4 Agronomic / Soil Chemistry Testing

At least one sample will be submitted from each of the HSA soil cover borings (BLD16-13AL, -14AL, and -15AL) listed at the bottom of **Table 4-1** for the agronomic/soil chemistry parameters summarized below. In addition, soil samples for agronomic and soil chemistry testing will be randomly analyzed from ~~three~~ five of the other geotechnical alluvial samples listed in **Table 4-1**. Agronomic properties are those characteristics that affect plant growth and are used to assess whether amendments are necessary to promote plant growth.

Therefore, the agronomic properties that could affect plant growth will be evaluated using the following testing:

- Arsenic, cadmium, molybdenum, soluble selenium, and uranium [Environmental Protection Agency (EPA) M6020)] for soil analysis;
- Boron, calcium, soluble magnesium, phosphorus, potassium and soluble sodium (EPA M6010B) for soil analysis;
- Cation Exchange Capacity [United State Department of Agriculture (USDA) No. 60 (19)] for soil analysis;
- Conductivity [Standard Method (SM2510B)] for soil analysis;
- pH (EPA 600/2-78-054 3.3.3) for soil analysis;
- Total Carbon and Total Organic Carbon [Agronomic Society of America (ASA) No.9 29-2.2.4)] for soil analysis;
- Organic Matter and Saturation Percent (USDA No. 60) for soil analysis;
- Sulfur (ASTM D4239-86C) for soil analysis;
- Nitrate as N (calculation);
- Nitrate/Nitrite and Nitrite as N (EPA M353.2); and
- Nitrogen and Ammonia (EPA M350.1).

Table 4-4 - Agronomic / Soil Chemistry Testing Program

Test/Method	Minimum Number of Samples	Comments
• Arsenic (EPA 6020) • Boron (EPA 6010B) • Cadmium (EPA 6020) • Calcium (EPA 6010B) • Cation Exchange Capacity (USDA No. 60 (19) • Magnesium, soluble (EPA 6010B) • Molybdenum (EPA 6020) • Phosphorus (EPA 6010B) • Potassium (EPA 6010B) • Selenium, soluble (EPA 6020) • Uranium (EPA 6020) • Conductivity (SM2510B) • pH (EPA 600/2-78-054-3.2.2 • Carbon, total (ASA No. 9 29-2.2.4)	~~5~~8	One sample will be randomly selected from each of the 3 HSA soil cover borings in **Table 4-1**. In addition, ~~2~~ 5 samples will be randomly selected from the other geotechnical samples in the alluvium from the HSA/RC borings and analyzed for agronomic and soil chemistry.

Test/Method	Minimum Number of Samples	Comments
• Carbon, total organic (ASA No. 9 29-2.2.4) • Organic Matter (USDA No. 60) • Saturation Percent (USDA No. 60) • Sulfur (ASTM D-4239-85C) • Nitrate as N (Calculation) • Nitrate/Nitrite (EPA 353.2) • Nitrite as N (EPA 353.2) • Nitrogen, ammonia (EPA 350.1)		

4.1.5 Ore Body Exploration

As proposed, fifty~~-three~~ (~~53~~50) borings will be drilled using RC methods to evaluate the geochemical and geotechnical properties of the overburden material and will penetrate through the Meade Peak Member of the Phosphoria Formation extending approximately 20 feet into the underlying Wells Formation. Drilling depths for these borings are generally expected to be between 250 to 400 feet bgs. Rock chip cuttings from the Meade Peak Member of the Phosphoria Formation will be collected at intervals specified by P4 and described in general accordance with P4 methods and/or the *United States Bureau of Reclamation Chapter 4 Classification of Rocks and Descriptions of Physical Properties of Rocks* (provided in Standard Operating Procedure [SOP-2]; **Appendix A**). No samples for non-P4 laboratory analysis will be collected from the Meade Peak Member for geochemical or geotechnical analyses as part of this plan. P4 may collect cuttings from the Phosphoria Formation for internal use. Field observations of rock description, physical properties, and other observations will be recorded on field sheets as provided in **Appendix B**.

4.2 BOREHOLE/TEST PIT ABANDONMENT

Standard borehole abandonment will be performed in accordance with IDAPA 37.03.09 Well Construction Standard Rules. The boreholes must be completely filled with approved seal material, which include~~s~~ using hydrated bentonite chips in those holes encountering groundwater otherwise borings may be filled using a combination of drill cuttings, bentonite and concrete. Concrete will be used to seal the upper 5 feet of the borehole. Test pits or trenches will be backfilled and compacted and covered with excavated soils immediately upon completion of the pit ~~This abandonment method will be used unless the State of Idaho requires a different abandonment method.~~

4.3 DECONTAMINATION

Equipment used for collecting samples such as split spoon samplers in the HSA borings will be decontaminated prior to all sample acquisition activities. Sampling equipment will be decontaminated as follows:

- Remove excess rock fragments, soil, sediment, and vegetation
- Wash equipment with Crystal White™ (or equivalent) biodegradable soap/deionized water solution
- Rinse with potable water
- Rinse three times with deionized water
- Allow equipment to air dry

All rinsate may be disposed of on~~-s~~Site. Field personnel will handle field equipment and containers carefully to minimize the potential for cross-contamination.

4.4 INVESTIGATION DERIVED-WASTE

Excess soil and rock cuttings, if not collected in the drill sump, will be shallow-spread at each drill site or placed back in the boring (if possible). Other wastes, such as personal protective equipment (PPE), empty bentonite bags, etc., will be disposed in trash dumpsters designated by P4.

4.5 SAMPLING LABELING AND HANDLING

4.5.1 Sample Labeling

All samples will be labeled in a clear, precise way for proper identification in the field and for tracking in the laboratory. The samples will have identifiable and unique numbers. The labels for off-Site laboratory analyses may contain the following information, as appropriate:

- Facility name;
- Sample number;
- Sample depth;
- Representative Formation;
- Date of collection;
- Time of collection;
- Initials or name of person(s) collecting sampling;
- Analytical parameter(s); and

- Method of sample preservation, as appropriate.

A coding system will be used to uniquely identify each sample collected. The system will allow for quick data retrieval and tracking to account for all samples. Samples will be numbered sequentially for each boring and type of sample collected. The sample designation will be recorded on the sample label and logbook, and will comprise two parts or fields.

- Part 1 will be a field of up to ~~nine~~ 10 characters corresponding to the assigned boring identification (e.g., BLD16-12GT). BLD for Ballard Mine, 16 for 2016, 12 for borehole number, GT for geotechnical borehole, V for vertical borehole, or AL for alluvial soil cover borehole.
- Part 2 is a six to eight-digit formation and depth interval identifier (e.g., DW-20-40).
    - Alluvium (AL)
    - Dinwoody (DW)
    - Rex Chert (RC)

As an example, sample designation bedrock sample from the Dinwoody Formation from boring BLD16-12GT, collected from the 75-80 feet bgs depth interval would be BLD16-12GT-DW-75-80.

4.5.2 Sample Handling and Shipping

After collection, samples will be properly stored to prevent degradation of the integrity of the sample prior to its analysis. As applicable, this includes proper containerization storing the sample in a refrigerated environment, and analyzing the sample within prescribed holding times. Sampling personnel will inventory the sample containers at the Site prior to shipment to make sure all samples listed on the chain-of-custody form are present.

All samples designated for off-~~site~~ Site laboratory analysis will be packaged and either delivered or shipped in accordance with applicable U.S. Department of Transportation (DOT) regulations. Samples will be sealed in the appropriate sampling container. Samples will be containerized in five-gallon buckets, bags, and/or laboratory supplied containers.

The originals of the analysis request and chain-of-custody forms will be sealed in a waterproof plastic bag and placed inside the shipping container prior to sealing the container. The sample buckets/containers will be taped shut using strapping tape over the hinges and custody seals placed across the top and sides of the cooler lid. Custody seals will be used to preserve the integrity of each sample container and cooler from the time the sample is collected until it is opened by the laboratory. Two or more custody seals will be signed, dated, and placed on the front and back of the sample cooler prior to transport. Clear tape will be placed over the custody seals to prevent inadvertent damage during shipping. The tape should not allow the seals to be lifted off with the tape and reaffixed without breaking the seal.

The geotechnical samples will be analyzed by Strata of Pocatello, Idaho. Contact information is:

2815 Garrett Way, Suite C
Pocatello, ID 83201
208.237.3400

Pace Analytical Services Inc. of Minneapolis, Minnesota will perform the geochemical analytical testing. Contact information is:

1700 Elm Street
Minneapolis, MN 55414
612.607.1700

4.5.3 Chain-of-Custody

Each sample will be properly documented to facilitate timely, accurate, and complete analytical analysis. The documentation system is used to identify, track, and monitor each sample from the point of collection through final data reporting. Where practicable, this documentation system may be electronic. Chain-of-custody protocols will be implemented and followed for samples submitted to off-~~site~~ Site laboratories. A sample is considered to be in a person's custody if it is: 1) in a person's physical possession, 2) in view of the person after taking possession, or 3) secured by that person so that no one can tamper with it.

Chain-of-custody forms will be used for sending or shipping samples to an off-Site laboratory to ensure that the integrity of samples is maintained. Each form will include the following information:

- Sample number;
- Date of collection;
- Time of collection;
- Sample depth;
- Testing requirements;
- Method of sample preservation;
- Number of sample containers;

- Recipient laboratories; and
- Signatures of parties relinquishing and receiving the sample at each transfer point.

Whenever a change of custody takes place from the sampler to the laboratory, both parties will sign and date the chain-of-custody form, with the relinquishing person retaining a copy of the form. For samples shipped by a courier, the laboratory that accepts the samples will inspect the chain of custody form and all accompanying documentation to ensure that the information is complete and accurate before signing the chain of custody form upon receipt of the samples. Any discrepancies will be noted on the chain-of-custody form.

4.6 PROJECT DOCUMENTATION

4.6.1 Field Logbooks

The on-~~site~~ Site geologist will use a weather-resistant, bound, survey-type field logbook with numbered, non-removable pages or hardcopy/electronic field forms to record field activities including geotechnical and geochemical sampling, drilling, etc. The following is an example of the information ~~to~~ that may be collected on the log sheets or log book:

- Dates and times;
- Name and location of the work activities;
- Weather conditions;
- Personnel, subcontractors and visitors on-~~-~~S~~s~~ite;
- Sample locations and methods (including sampling equipment), time of sample collection, and sample depths;
- Samples submitted to the laboratory for analyses;
- Name of carrier transporting the sample (e.g., name of laboratory and shipping carrier);
- Photograph numbers and descriptions (if applicable);
- Description of decontamination activities (if applicable);
- Any deviations from this plan;
- Health & Safety meetings including topics discussed and attendees;
- Accidents including near misses;
- Other relevant observations as the field work progresses; and
- Problems and corrective actions.~~; and~~

At the end of each field day, the project field book will be dated and signed by the field person that recorded notes during the day. If the entire page is not used a line will be drawn through the unused portion of the page. If pages are accidentally skipped, a line will be drawn through the entire page. All corrections will be made by drawing a line through the erroneous information and initialing the change. "White-out" or its equivalent will not be used.

4.6.2 Photo Logs

Digital photographic records of soil and rock samples and general field activities shall be collected throughout the drilling program to document the day's events and to preserve relevant data. An engineer's scale or tape shall be included in any photographs taken of soil and rock samples.

4.6.3 Boring/Test Pit Logs

After collecting the required samples for geotechnical and/or geochemical analyses, the field geologist will make a visual description of the lithologic or physical characteristics of the soil samples or rock chips. Lithologic or physical characteristics will include but are not limited to color, grain size (as applicable), plasticity, density, soil moisture, odors, bedding, formation change, and other information needed to accurately describe the borehole lithology. The ~~drill~~ cuttings will be logged for material or rock type and depth (if any), soil/rock classification, and the interface between soil and bedrock, formation changes/contacts, and/or groundwater. As well as providing a visual description of the drill core/cuttings, other information that may be entered on the Borehole Lithology/Test Pit Logs may include:

- Boring ID number;
- A sketch of the boring location;
- Project name and job number;
- Date drilled and date completed;
- Logged by;
- Total depth of the boring;
- Diameter of boring;
- Drilling contractor;
- Drilling method;
- Boring abandonment procedure;

- Number of blows to drive sampler (if applicable);
- Drill advance rate;
- Sampler type (as applicable); and
- Amount of material recovered per depth interval.

The borings and test pits will be drilled or excavated in accordance with SOP-1 and SOP-3 in **Appendix A**, respectively.

4.6.3.1 Soil Classification

Soil will be described in general accordance with the USCS and the ASTM Standard D 2488 - 90 Standard Practice for Description and Identification of Soils (Visual-Manual Procedure; ASTM, 1990). A detailed description of soil classification that includes the information listed below is described in detail in SOP-2 in **Appendix A**. A detailed description of soils may be difficult when encountering alluvium in the RC holes due to the recovery method.

Field observations of soil classification and other observations will be recorded on field sheets similar to the Borehole and Test Pit Lithology Logs and Sampling Forms located in **Appendix B**. Information included on the field forms will include the following, as appropriate:

- USCS Group symbol (GW, GP, GM, GC, SW, SP, SM, SC, ML, CL, OL, MH, CH and OH);
- USCS name (silty gravel, silty fine sand, poorly graded sand, etc.);
- Color (Munsell Chart);
- Angularity of coarse-grained soil;
- Particle size range and percentage (boulders, cobbles, gravel, sand, fines);
- Plasticity (non-plastic, low, medium, high);
- Density (for clay, silt and sand);
- Moisture content (dry, moist, wet);
- Noticeable odors (if any);
- Structure (stratified, laminated, fissured);
- Hardness of coarse particles;
- Cementation (if present);
- Dry strength (none, low, medium, high, very high);
- Dilatancy (none, slow, rapid);

- Minerals (if present); and
- Graphic log of bedding, lithological changes, fractures, gouge, organics such as roots and the location of other physical features.

4.6.3.2 Rock Classification

Rock chips will be described in general accordance with P4 methods and/or the *Classification of Rocks and Descriptions of Physical Properties of Rocks* (U.S Department of Interior Bureau of Reclamation, 2001) (provided in SOP-2; **Appendix A**). Field observations of rock descriptions and physical properties and other observations will be recorded on field sheets similar to the Borehole Lithology Logs (see **Appendix B**). Information included on the field forms will include the following, as appropriate:

- Rock unit/formation name;
- Rock type identification;
- Weathering;
- Color (e.g., Munsell Chart);
- Durability index ;
- Hardness / strength;
- Sedimentary and pyroclastic rock particle size;
- ~~Igneous and metamorphic rock texture;~~
- Discontinuity;
- Structure (stratified, laminated, fissured);
- Cementation (if present);
- Dry strength (none, low, medium, high, very high);
- Deleterious minerals;
- Minerals (if present);
- Graphic log of bedding, changes of rock type, fractures, organics such as roots and the location of other physical features; and
- Reaction with HCl (none, weak, strong).

4.7 SURVEYING

Boring locations will be surveyed using a survey grade global positioning system (GPS) unit. All measurements will be referenced to modified State Plane Coordinate System Idaho East, North American Datum 1983, feet. Each sampling location will be marked with a wooden stake, a wooden lath or pin flag and will have the corresponding boring number written on the marker. During surveying, the northing, easting and elevation will be stored in the GPS unit and downloaded onto a computer and provided to the P4 Project Manager. The GPS unit will be checked for accuracy following Site procedures.

4.8 FIELD CHANGE REQUEST

Due to the conditions associated with field sampling activities, unexpected situations may occur that will require deviations or modifications to the requirements of this SAP. In such situations, the P4 Project Manager may authorize the on-Site geologist or designee to undertake modifications necessary to complete individual drilling tasks. The scope and reasoning behind minor modifications will be discussed in the summary report prepared following the exploration program. Major changes or deviations ~~(e.g., adding or excluding a borehole)~~ in the field program (e.g., adding or excluding a borehole or adding a test pit) will be discussed with the USEPA Project Manager.

4.9 PROJECT SCHEDULE

As shown on the proposed schedule in **Figure 4-1**, it is anticipated that drill rigs will be mobilized to the Ballard Site in June 2016. Drilling and sampling activities are assumed to span three months. Laboratory data will be complete approximately three months after the end of the field program. A draft drilling report as discussed in Section 5.7 will be developed and submitted to the A/Ts in late 2016/early-2017.

Figure 4-1
Ballard Mine Exploration Plan Project Schedule

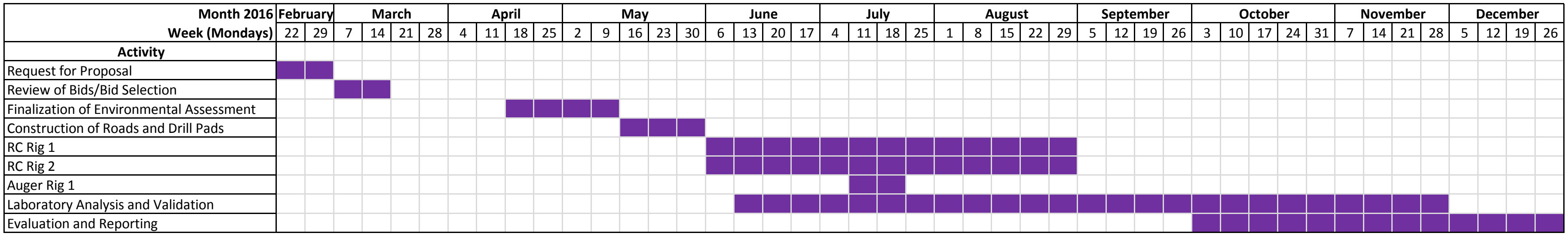

Table 4-1 Drilling and Sampling Summary

Drill Hole ID	CERCLA Rationale (see key below)	Estimated Depth to Meade Peak Member (ft)	Estimated Depth to Groundwater (ft)	Estimated Total Depth (ft)	Location		Possible Formations Encountered and Estimated Thicknesses (ft)						Drill and Sample Information		Geochemisty (as necessary) Sampling					Geotechnical (as necessary) Sampling			
					Easting	Northing	Topsoil	Alluvium	Dinwoody Fm	Rex Chert Member	Meade Peak Member	Wells Fm	Drill Rig Type	Estimated Sample Intervals (ft)	Rex Chert Member		Dinwoody Fm		Alluvium	Geotechnical Parameters		Additional Geotechnical and Agronomic Parameters	
															ABA/ Whole Rock	SPLP (30% of samples)	ABA/ Whole Rock	SPLP (30% of samples)	SPLP (30% of samples)	Alluvium	Dinwoody Fm	Alluvium	Dinwoody Fm
BLD16-01V1	CM/GW	60	?	260	840,396	421,847	2-5			55-60	180	20	RC	20									
BLD16-02V1	CM/GW	75	?	300	839,910	422,127	2-5			75-90	180	20	RC	20									
BLD16-03V1	CM/GW	80	?	315	839,707	422,285	5			90	180	20	RC	20	1	TBD							
BLD16-04V1	EO/GW	SURFACE	?	150	840,078	423,531					130	20	RC	20									
BLD16-05V1	EO/GW	SURFACE	?	180	840,025	422,641					160	20	RC	20									
BLD16-06V1	CM/GW	30	?	225	840,281	422,327	2-5			10-20	180	20	RC	20									
BLD16-07V1	CM/GW	100	?	325	840,848	422,136	5	90		10-20	180	20	RC	20					TBD	TBD		TBD	
BLD16-08V1	CM/GW	25-50	?	275	841,068	422,577	2-5	?		25-50	180	20	RC	20									
BLD16-09V1	CM/GW	25-50	?	275	841,453	422,320	2-5	?		25-50	180	20	RC	20									
BLD16-10V1*	CM/GW	25-50	?	105	841,447	421,900	5	50-75		10-25			RC	20					TBD	TBD		TBD	
BLD16-11A1*	CM/DT/GW	210 (~75ft of dump)	?	135	843,030	422,269		?		135			RC	20									
BLD16-11V1*	CM/DT/GW	175 (~60ft of dump)	?	115	843,032	422,269		?		115			RC	20	1	TBD			TBD	TBD		TBD	
BLD16-12V1	CM/DT/GW	175 (~40ft of dump)	?	375	842,911	422,587		?		135	180	20	RC	20									
BLD16-13A1	CM/GW	225	?	445	842,466	423,624	5-10	10-20		210	185	20	RC	20									
BLD16-13V1	CM/GW	220	?	415	842,466	423,624	5-10	10-20		200	180	20	RC	20					TBD	TBD		TBD	
BLD16-14A1	CM/GW	180	?	390	842,202	423,534				185	185	20	RC	20									
BLD16-14V1	CM/GW	175	?	380	842,202	423,534				180	180	20	RC	20									
BLD16-15A1	CM/GW	55	?	265	842,062	423,474	2-5	5-10		50	185	20	RC	20									
BLD16-15V1	CM/GW	55	?	260	842,062	423,474	2-5	5-10		50	180	20	RC	20	1	TBD							
BLD16-16A1	CM/GW	205	?	410	842,186	424,044		?		205	185	20	RC	20									
BLD16-16V1	CM/GW	200	?	400	842,187	424,044		?		200	180	20	RC	20					TBD	TBD		TBD	
BLD16-17A1	CM/GW	165	?	365	842,008	423,980	2-5	5-10		155	185	20	RC	20									
BLD16-17V1	CM/GW	160	?	360	842,008	423,980	2-5	5-10		150	180	20	RC	20									
BLD16-18A1	CM/GW	55	?	265	841,796	424,007	2-5	5-10		50	185	20	RC	20									
BLD16-18V1	CM/GW	55	?	260	841,796	424,007	2-5	5-10		50	180	20	RC	20	1	TBD							
BLD16-19A1	CM/GW	220	?	425	842,222	424,362	5	5-10		210	185	20	RC	20									
BLD16-19V1	CM/GW	210	?	410	842,222	424,362	5	5-10		200	180	20	RC	20									
BLD16-20A1	CM/GW	165	?	365	841,909	424,349	5	5-10		155	185	20	RC	20									
BLD16-20V1	CM/GW	160	?	360	841,910	424,348	5	5-10		150	180	20	RC	20									
BLD16-21A1	CM/GW	295	?	500	842,290	424,890	5	10-20	40	230	185	20	RC	20									
BLD16-21V1	CM/GW	285	?	485	842,290	424,890	5	10-20	40	220	180	20	RC	20	2	TBD	1	TBD	TBD	TBD		TBD	
BLD16-22A1	CM/GW	220	?	425	842,044	424,787	5	5-10		210	185	20	RC	20									
BLD16-22V1	CM/GW	210	?	410	842,044	424,787	5	5-10		200	180	20	RC	20									
BLD16-23A1	CM/GW	165	?	365	841,778	424,683	5	5-10		155	185	20	RC	20									
BLD16-23V1	CM/GW	160	?	360	841,778	424,683	5	5-10		150	180	20	RC	20									
BLD16-24A1	CM/GW	275	?	480	841,901	425,181	5	10-20	20	230	185	20	RC	20									
BLD16-24V1	CM/GW	265	?	465	841,901	425,181	5	10-20	20	220	180	20	RC	20			1	TBD	TBD	TBD		TBD	
BLD16-25A1	CM/GW	85	?	300	841,453	425,015	2-5	5-10		80	185	20	RC	20									
BLD16-25V1	CM/GW	75	?	290	841,453	425,015	2-5	5-10		75	180	20	RC	20	1	TBD							
BLD16-26A1	CM/GW	220	?	425	841,684	425,572	5	5-10		210	185	20	RC	20									
BLD16-26V1	CM/GW	210	?	410	841,684	425,572	5	5-10		200	180	20	RC	20									
BLD16-27A1	CM/GW	275	?	480	841,756	425,800	5	10-20	20	230	185	20	RC	20									
BLD16-27V1	CM/GW	265	?	465	841,756	425,800	5	10-20	20	220	180	20	RC	20			1	TBD	TBD	TBD		TBD	
BLD16-28A1	CM/GW	220	?	425	841,520	425,990	5	5-10		210	185	20	RC	20									
BLD16-28V1	CM/GW	210	?	410	841,520	425,990	5	5-10		200	180	20	RC	20	2	TBD							
BLD16-29A1	CM/GW	165	?	365	841,353	425,743	5	5-10		155	185	20	RC	20									
BLD16-29V1	CM/GW	160	?	360	841,353	425,743	5	5-10		150	180	20	RC	20									
BLD16-30V1	CM/GW	55	?	260	840,728	425,665	2-5	5-10		50	180	20	RC	20									
BLD16-31A1	CM/GW	55	?	265	840,507	425,926	2-5	5-10		50	185	20	RC	20									
BLD16-31V1	CM/GW	55	?	260	840,507	425,926	2-5	5-10		50	180	20	RC	20	1	TBD							
BLD16-32V1	CM/GW	55	?	260	840,328	426,154	2-5	5-10		50	180	20	RC	20									
BLD16-33V1	CM/DT/GW	80 (~60ft of dump)	?	280	841,216	427,234		5-10	65	10	180	20	RC	20			1	TBD					
BLD16-34V1	CM/GW	50	?	250	839,883	421,788		5-10		45	180	20	RC	20									
BLD16-01GT	CM/GT	NO	NO	80	841,952	426,453	X	?	X				Auger (SS)	5			TBD	TBD	TBD	TBD	TBD	TBD	
BLD16-02GT	CM/GT	NO	NO	80	842,228	425,990	X	?	X				Auger (SS)	5			TBD	TBD	TBD	TBD	TBD	TBD	
BLD16-03GT	CM/GT	NO	NO	80	842,387	425,196	X	?	X				Auger (SS)	5			TBD	TBD	TBD	TBD	TBD	TBD	
BLD16-04GT	CM/GT	NO	NO	80	842,201	424,961	X	?	X				Auger (SS)	5			TBD	TBD	TBD	TBD	TBD	TBD	
BLD16-05GT	CM/GT	NO	NO	80	842,594	423,891	X		X				Auger (SS)	5			TBD	TBD			TBD		
BLD16-06GT	CM/GT	NO	NO	80	841,358	421,958	X	X	X				Auger (SS)	5			TBD	TBD	TBD	1	TBD	1	
BLD16-07GT	CM/GT	NO	NO	80	840,903	421,792	X		X				Auger (SS)	5			TBD	TBD			TBD		
BLD15-08GT	CM/GT	NO	NO	80	839,384	424,740	X		X				Auger (SS)	5			TBD	TBD			TBD		
BLD16-09GT	CM/GT	NO	NO	80	839,517	423,674			X				Auger (SS)	5			1	TBD			TBD		
BLD16-10GT	CM/GT	NO	NO	80	839,302	425,019			X				Auger (SS)	5			1	TBD			TBD		
BLD16-11GT	CM/GT	NO	NO	80	839,488	425,287	X		?				Auger (SS)	5			TBD	UK			UK		
BLD16-12GT	CM/GT	NO	NO	80	839,981	421,374	X		X				Auger (SS)	5			1	TBD			TBD		
BLD16-13AL	SC	NO	NO	50	840,116	422,414	X	X					Auger (SS)	5					TBD	1		1	
BLD16-14AL	SC	NO	NO	50	838,521	421,102	X	X					Auger (SS)	5					TBD	1		1	
BLD16-15AL	SC	NO	NO	50	841,434	422,531	X	X					Auger (SS)	5					TBD	1		1	
														Estimated Sample Count	10	3	12	4	3	10	10	8	0

CM= Cover Material
DT= Dump thickness
EO= Exposed pit ore
GW= Ground Water
GT= GeoTech
SC= Soil Cover
SS= Split Spoon
TBD= To be determine sample collection based on field observations and professional judgement
?=unknown whether material exists at that location
X=formation expected to be encountered at this location, formation thickness unknown
*Boring not intended to drill through the Meade Peak Formation

5.0 QUALITY ASSURANCE PROJECT PLAN

This section presents the QAPP as it pertains to soil sample collection, handling and testing of the soil samples for geotechnical and geochemical properties.

5.1 PROJECT TEAM AND ORGANIZATION

The overall organizational structure and key personnel for this investigation and responsibility and authority of each team member is presented below.

5.1.1 A/Ts Responsibilities

The USEPA administers the RI/FS for the P4 Sites. The USEPA will review and approve this ~~site~~Site-specific work plan. The USEPA's Project Manager is Dave Tomten. Communication with the A/Ts will be coordinated by the USEPA Project Manager.

5.1.2 P4 Project Manager

Molly Prickett is the P4/Monsanto Project Manager and is responsible for coordinating the necessary resources at the Ballard Mine to accomplish the investigation elements of the project. Ms. Prickett will be responsible for ensuring that the necessary resources are dedicated to the project and will assure the technical, budget, and schedule requirements are met.

5.1.3 Field Investigation Manager

David Carpenter will serve as the P4 Field Investigation Manager. Mr. Carpenter will oversee field activities to make sure the borings are drilled and investigation samples are collected at the Ballard Mine per the requirements established herein. Mr. Carpenter will report directly to the P4 Project Manager.

5.1.4 Data Quality Assurance Manager

Elizabeth Van Pelt (MWH) will be responsible for quality assurance (QA) oversight of analytical programs. Ms. Van Pelt will coordinate sample receipt, management, analytical laboratory submittal, and third party validation. She will also make sure the analytical programs and data quality meet project requirements and is responsible for database management.

5.2 ANALYTICAL METHOD REQUIREMENTS

For each soil/rock cuttings sample, the contracted laboratory will prepare soil samples consistent with agreed upon SOPs consistent with the specified analytical method. Subsamples will be obtained for matrix spikes prior to sample preparation and analysis. **Table 4-2**, **Table 4-3**, and **Table 4-4** provide a list of the target analytes and test methods.

5.3 QUALITY CONTROL REQUIREMENTS

5.3.1 Field Quality Control Samples

Field duplicates/replicates for each sample matrix will be collected at a rate of ten (10) percent of the number of primary geochemical samples, and matrix spike and matrix spike duplicate pairs will be collected at a rate of five (5) percent of the number of primary samples for geochemical samples.

5.3.1.1 Equipment Rinsate Blanks

Blanks are defined as sample material that is free of reportable concentrations of target analytes; the blanks are introduced at various stages of sample handling to monitor possible contamination introduced by various field activities. Only equipment rinsate blanks will be used for this project from split spoon sampling equipment used to collect geotechnical/agronomic/soil chemistry samples (HSA borings). An equipment rinsate blank is a sample of the deionized water being used by the field team that is collected using decontaminated sampling equipment. The equipment rinsate blank sample will be analyzed for the same analytes that are analyzed in the primary sample.

5.3.1.2 Replicate Sampling

A true field duplicate is a subsample that has been divided from the primary sample. Field duplicate samples provide information on the precision of the sampling, transfer, and analytical process. At 10 percent of sampling locations, a field replicate of soil/rock samples will be collected (twice the mass) and split using cone and quartering or other standard splitting procedures.

5.3.2 Laboratory Quality Control Samples

Laboratory quality control sample protocols will follow procedures and requirements established in the *Radiological Site and Background Investigation Quality Assurance Project Plan* (MWH, 2014) and will include the following, as appropriate:

- Calibration blanks - initial, second source, continuing

- Tune
- Method blanks
- Matrix spikes
- Laboratory control samples (verification solutions), and
- Laboratory duplicate samples.

5.4 MODIFICATIONS AND DEVIATIONS

Any significant changes to the QAPP will be documented and approved by the P4 Project Manager and USEPA Project Manager. Minor deviations from the QAPP will be documented in field notes and identified in the data report as further discussed in Section 5.7.

5.5 DATA VALIDATION AND USABILITY

The following definitions are provided in *Guidance for Quality Assurance Project Plans* (USEPA, 2002):

- Verification – the process of evaluating the completeness, correctness, and conformance/compliance of a specific data set against the method, procedural, or contractual specifications.
- Validation – an analyte- and sample-specific process that extends the evaluation of data beyond method, procedural, or contractual compliance (i.e., data verification) to determine the analytical quality of a specific data set.

Based on these definitions, the 3rd-party validator technically will be performing data verification of the sample, calibration, and quality control (QC) data provided by the laboratory against the criteria specified in this QAPP. Validation will be performed on the geochemical analyses in **Table 4-2**. The validator will use the *USEPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review* (USEPA, 2014) as a basis for performing data verification and qualification of data. The validator will document the data verification process on their in-house worksheets and summarize the results in data validation reports.

The validator will use the following data qualifiers ("USEPA Flag"):

U	The analyte was analyzed for, but was not detected above the level of the reported sample quantitation limit.
J	The result is an estimated quantity. The associated numerical value is the approximated concentration of the analyte in the sample.
J+	The result is an estimated quantity, but the result may be biased high.
J-	The result is an estimated quantity, but the result may be biased low.
R	The result is unusable. The sample result is rejected due to serious deficiencies in

meeting quality control criteria. The analyte may or may not be present in the sample.

UJ The analyte was analyzed for, but was not detected. The reported quantitation limit is approximate and may be inaccurate or imprecise.

And the following "Reason Codes":

1	Holding Time
2	Sample Preservation (including receipt temperature)
3	Sample Custody
4	Missing Deliverable
5	ICPMS Tune
6	Initial Calibration
7	Initial Calibration Verification
8	Continuing Calibration Verification
9	Low-Level Calibration Check Sample
10	Calibration Blank
11	Laboratory or Preparation Blank
12	ICPMS or ICP Interference Check Standard
13	Laboratory Control Sample or Laboratory Control Sample Duplicate Recovery
14	Laboratory Control Sample Precision
15	Laboratory Duplicate Precision
16	Matrix Spike or Matrix Spike Duplicate Recovery
17	Matrix Spike/Matrix Spike Duplicate Precision
18	ICPMS or ICP Serial Dilution
19	ICPMS Internal Standard
20	Field Replicate Precision
21	Equipment Rinsate Blank
22	Linear Range Exceeded
23	Other reason
24	Result is less than the MDC
25	Result is less than two times the error

The validator will populate an MWH-supplied EDD with the following data:

- Field Header "USEPA Flag": Populate with USEPA flags specified above and in template reports.

- Field Header "Reason Code": Populate with all applicable Reason Codes as specified above and in template reports.
- Field Header "Final Result": Populate with the final, qualified result, including any adjustment based on blank contamination.

The validator will perform USEPA Stage 2B verification/validation (USEPA, 2009) on approximately 90 percent of sample data and USEPA Stage 4 verification/validation on the remaining 10 percent of sample data. The Data Quality Assurance Manager will take the lead on validating the verified data.

5.6 AUDITS OF FIELD AND LABORATORY ACTIVITY

5.6.1 Field Audit

The P4 Project Manager or designee will conduct an on~~-s~~Site system audit of field sampling practices during sampling activities. Any nonconformance observed in the audit will be documented and resolved. The A/Ts may request and/or carry out additional field audits. Any nonconformance with approved sampling requirements that may be observed in the field audit will be promptly evaluated and resolved.

5.6.2 Laboratory Audits

Laboratory performance audit samples will not be prepared for this ~~site~~ Site characterization. On-~~site~~ Site audits of the laboratories are not scheduled to be conducted. The A/Ts may request and/or carry out laboratory audits.

5.6.3 Independent Technical Review

An independent technical review will be performed by the P4 Project Manager or designee for all draft and final project reports. All comments will be resolved and incorporated prior to final submittals.

5.7 REPORTING

Following completion of the program, a draft drilling report will be prepared and submitted by P4 for A/T review. The report will summarize the results of the geochemical, geotechnical, agronomic/soil chemistry exploration program. Information provided in the report will include summary tables of analytical results, boring logs, photographic logs, geologic cross-sections, interpretation of data and field observations, estimates of cover material quantities and potential use(s) and of ore body extent in the Ballard mine area. In addition, the report will include quality assurance reporting including any corrective actions, laboratory analysis data, and data validation reports. A final report will be prepared following A/T review and incorporation of comments.

6.0 HEALTH AND SAFETY PLAN

Safety procedures for the ~~site~~ Site investigation are described in the Monsanto 6.0 Contractor/Guest ES&H Site Guidelines. The mine-specific safety requirements involve a training orientation for hazard recognition and avoidance will be provided to each contractor coming on Site.

7.0 REFERENCES

MWH Americas, Inc. (MWH), 2011. *Ballard, Henry and Enoch Valley Mines, Remedial Investigation and Feasibility Study Work Plan*. Final Revision 2. Prepared for P4 Production LLC. May.

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MWH Americas, Inc. (MWH), 2014b. *Remedial Investigation Report for P4's Ballard Mine*. Final Revision 2. Prepared for P4 Production LLC. November.

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U.S. Geological Survey (USGS) and U.S. Forest Service (USFS), 1977. *Final Environmental Impact Statement, Development of Phosphate Resources in Southeastern Idaho*. Volumes I, II, III, and IV. United State Department of the Interior, Washington, D.C.

APPENDICES

APPENDIX A

STANDARD OPERATION PROCEDURES

STANDARD OPERATING PROCEDURE 1

SOIL BORING AND DRILLING

STANDARD OPERATING PROCEDURE 11

SOIL BORING AND DRILLING

TABLE OF CONTENTS

1.0 INTRODUCTION

This standard operating procedure (SOP) provides a description of the principles and applicability of standard soil boring drilling procedures used during field investigations. Subsurface borings are typically installed to collect soil samples for chemical or geotechnical purposes, to collect subsurface stratigraphic information, and to install vadose zone or groundwater monitoring wells. The purpose of this SOP is to aid in the selection of drilling methods appropriate for site-specific conditions. It is intended to be used by the MWH Project Manager (PM) and the Field Team Leader (FTL) and site geologist/hydrogeologist to develop an understanding of each method sufficient to permit project planning, scheduling, subcontracting, and resource planning.

This SOP focuses on methods and equipment that are readily available and typically applied in drilling activities. It is not intended to provide an all-inclusive discussion of subsurface boring drilling methods. Two general methods are discussed: 1) methods that do not use circulating fluids, and 2) methods requiring the circulation of drilling fluids to transport cuttings to the surface. A discussion of key considerations in the selection of a suitable subsurface boring method is also presented. Table 11-1 provides a summary of drilling methods that are applicable to various geologic settings. All drilling locations will be cleared by local utility locators, where applicable, and property owners.

2.0 DEFINITIONS

Auger: A hollow or solid tubular steel center shaft around which is welded a continuous steel strip in the form of a helix. A center bit is used inside the auger to prevent soil from entering the hollow-stem auger.

Bailer: A cylindrical tool designed to remove groundwater from a borehole. A valve at the bottom of the bailer retains the material in the bailer. The three types of bailers are a flat-valve bailer, a dart-valve bailer, and a sand pump with rod plunger.

Cone Penetrometer: An instrument used to identify the subsurface conditions by measuring the differences in the resistance and other physical parameters of the strata. The cone penetrometer consists of a conical point attached to a drive rod of smaller diameter. Penetration of the cone into the formation forces the soil aside, creating a complex shear failure.

Cuttings: Formation particles removed from a borehole during the drilling process.

Drilling Fluids or Muds: A water-based or air-based fluid used in the soil boring operation to remove cuttings from the borehole, to clean and cool the bit, to reduce friction between the drill string and the sides of the borehole, and to seal and stabilize the borehole.

Drill Flight: An individual drill section, typically 5-20 feet in length.

Heaving Formation: Unconsolidated, saturated substrate encountered during drilling where the hydrostatic pressure of the formation is greater than the borehole pressure causing the substrate to move up into the borehole.

Kelly Bar: A solid steel bar or pipe that is the main section of drill string to which the power is directly transmitted from the rotary table to rotate the drill pipe and bit. The cross section of the kelly bar is either square, hexagonal, or grooved. The kelly bar works up and down through drive bushings in the rotary table.

Pitch: The distance along the axis of an auger flight that it takes for the helix to make one complete 360-degree turn.

Rotary Table: A mechanical or hydraulic assembly that transmits rotational torque to the kelly bar, which is connected to the drill pipe and the bit. The rotary table has a hole in the center through which the kelly bar passes.

Split-Spoon Sampler: A thick-walled, steel tube split lengthwise that is used to collect soil samples. The split-spoon sampler is commonly lined with brass or stainless steel sample sleeves and is driven or pushed down hole by the drill rig to collect samples.

Shelby Tube: A devise used to collect undisturbed soil samples for geotechnical analysis. This thin-walled sampler minimizes disturbance that results from displacement and friction of soil samples.

3.0 RESPONSIBILITIES

This section presents a brief definition of field roles, and the responsibilities generally associated with them. This list is not intended to be comprehensive and often, additional personnel may be involved. Project team member information will be included in project-specific plans (e.g., work plan, field sampling plan, quality assurance plan, etc.), and field personnel will always consult the appropriate documents to determine project-specific roles and responsibilities. In addition, one person may serve in more than one role on any given project.

MWH Project Manager: Selects site-specific drilling methods with input from other key project staff and stakeholder personnel. Prepares technical provisions for drilling subcontracts.

MWH Quality Control Manager: Performs project audits. Ensures project-specific data quality objectives are fulfilled.

MWH Field Team Leader (FTL) and/or Field Geologist, Hydrogeologist, or Engineer: Implements the field program and supervises other field staff. Prepares daily logs of field activities.

MWH Field Technician (or other designated personnel): Assists the FTL and/or geologist, hydrogeologist, or engineer in the implementation of field tasks.

4.0 DRILLING METHODS

A field log will be maintained during all drilling activities. Examples of soil and rock boring log forms are included at the end of this SOP. Drilling methods can be separated into two general types; techniques that do not use circulating fluids and techniques that use circulating fluids. The following sections discuss the drilling methods that fall into each of these two general categories.

4.1 DRILLING METHODS WITHOUT CIRCULATING FLUIDS

4.1.1 Auger Drilling

Auger drilling is accomplished by rotating a pipe or rod that has a cutting bit. The common auger drilling methods discussed in this section are hand, continuous-flight, hollow-stem, and bucket.

Hand Auger: A hand auger typically cuts a 3.5-inch diameter and, depending on the geologic materials, up to 15-feet deep borehole, though typically the borehole is less than 10-feet deep. Generally, the borehole cannot be advanced below the water table because of potential collapse.

<u>Applications</u>

- Shallow (up to 15 feet deep) soil investigations

- Soil sampling for stratigraphic logging
- Water-bearing zone/water table identification.

Limitations

- Limited to very shallow depths
- Unable to penetrate dense or gravelly soil
- Borehole stability difficult to maintain
- Labor intensive.

Continuous-Flight Augers: Continuous-flight augers consist of a plugged tubular steel center shaft around which is welded a continuous steel strip in the form of a helix. An individual auger is known as a "flight" and is generally 5 feet long. Auger drill heads (bits) are generally designed to cut a hole 10 percent greater in diameter than the actual diameter of the auger. In addition to diameter, augers are specified by the pitch of the auger, and the shape and dimension of the connections.

The rotation of the augers causes the cuttings to move upward, which can be "smeared" along the borehole walls. This smearing may effectively seal off the upper zones, thereby reducing the possibility of cross contamination of the upper zones to the deeper zones but increases the possibility of deep to shallow contamination. Conversely, smearing of clays on the borehole walls may seal off aquifers to be monitored.

Applications

- Relatively shallow soil investigations (up to 150 feet, depending on site conditions and type of drill rig)
- Soil sampling for stratigraphic logging
- Installation of vadose zone monitoring wells
- Installation of groundwater monitoring wells in stable soils
- Identification of depth to bedrock.

Limitations

- Soil sampling difficult, labor intensive, and limited to areas of relatively stable soils
- Difficult to install monitoring wells in unstable soils
- Depth capability decreases as diameter of auger increases
- Monitoring well diameter limited by auger diameter.

Hollow-Stem Augers: Hollow-stem augers (HSA) are commonly used in unconsolidated materials up to 150 feet in depth. A key advantage of HSA drilling is that undisturbed soil samples can be collected through the augers, which act as a temporary outer casing during soil boring drilling. The augers also act as a temporary outer casing during monitoring well installation.

Hollow-stem augers consist of two parts: a tube with flights attached to the outside and connected to the lead auger, and a center rod and bit which prevents soil from entering the center of the auger. The removable inner plug is the primary advantage of this drilling method. Withdrawing the center bit while leaving the auger in place provides an open, cased hole into which soil samplers, down-hole drive hammers, instruments, casing, wire, pipe, or numerous other items can be inserted. Replacing the center bit allows for continuation of the borehole.

Hollow-stem augers are specified by the inside diameter of the hollow stem, not by the hole size it drills. Hollow-stem augers are available in a variety of inside-diameters, such as 2.5, 3.25, 3.375, 4.0, 4.25, 6.25, 6.625, 8.25, and 10.25 inches. The most commonly used sizes are 3.25 inches and 4.25 inches for soil borings.

The rotation of the augers causes the cuttings to move upward, which can be "smeared" along the borehole walls. This smearing may effectively seal off the upper zones, thereby reducing the possibility of cross contamination of the upper zones to the deeper zones but increases the possibility of deep to shallow contamination. Conversely, smearing of clays on the borehole walls may seal off aquifers to be monitored.

<u>Applications</u>

- Suitable for soil investigations with soils ranging in consistency from clays to fine gravels
- Allows good soil sampling with split-spoon samplers or Shelby tubes

- Monitoring well installation in all unconsolidated formations
- Can serve as temporary casing
- Can be used in stable formations to set surface casing.

Limitations

- Difficulty in preserving sample integrity in heaving formations
- Formation invasion by water or drilling mud if used to control heaving
- Possible cross contamination of aquifers where the annular space is not positively controlled by water, drilling mud or surface casing
- Limited diameter of augers limits casing size
- Smearing of clays may seal off aquifer to be monitored.

Bucket Auger: Bucket augers have a depth capacity of 30 to 75 feet, and are used for large diameter soil borings of about 16 to 48 inches. They are not normally used to drill monitoring wells or for soil sampling, but may be used to drill production and recovery wells. In addition, they may also be used to set large diameter conductor or surface casings for production and monitoring wells.

Applications

- Drilling of large diameter boreholes to a maximum depth of 75 feet
- Drilling in unconsolidated formations.

Limitations

- Difficult to advance the borehole below the water table
- Consolidated formations and cobbles are difficult to drill
- Loose sand formations may slough during drilling.

4.1.2 Sonic Drilling

Sonic drilling is a method of drilling where holes are created by rotating and vibrating the drill bit at specific frequencies. Sonic drilling is commonly used for drilling in unconsolidated material up to 200 feet deep. Boulders and cobbles within the unconsolidated material can be cored through using the sonic vibration and water to cool the drill bit. Sonic drilling provides a continuous soil core and allows for more effective identification of lithology, water bearing units, and delineation of potential contamination.

The sonic drilling method consist of two parts: a removable inner tube which is advanced into the soil and retains the soil inside of the tube. This inner tube is extracted to retrieve the soil core. Casing is advanced after the retrieval of the inner tube that cases the soil boring to prevent caving of the unconsolidated material. Sizes for the sonic core are 3, 4, 6, 7, and 8 inch and casing can be up to 12 inches in diameter. Soil cores are typically retained in plastic tubes that are opened to expose the soil.

<u>Applications</u>

- Suitable for soil investigations with soils ranging in consistency from clays to gravel
- Allows good soil sampling and recovery by providing a continuous core
- Monitoring well installation in all formations
- Can be used to drill through cobbles and boulder size material
- Allows for casing off contaminated zones
- Can be used in unstable formations to set surface casing.

<u>Limitations</u>

- Smearing of clays may seal off aquifer to be monitored
- Cannot take undisturbed soil samples
- Cannot core into bedrock.

4.1.3 Percussion Drilling

Percussion drilling is a form of drilling where the basic method of advance is hammering, striking, or "beating" the drilling rods into the formation. Common percussion methods that do not use circulating fluids are cable-tool, and driven boreholes.

Cable-Tool Drilling: Cable-tool drilling operates by alternately raising and dropping a bit, hammer, or other heavy tool. In consolidated formations, the drill bit breaks or crushes the formation. In unconsolidated formations, the drill bit primarily loosens the formation when drilling. In both instances, the reciprocating action of the tools mixes the crushed or loosened particles with water to form a slurry or sludge at the bottom of the borehole. If little or no water exists in the penetrated formation, water is added to form the slurry. Slurry accumulation increases as drilling proceeds and eventually it reduces the impact of the tools. When the thickened slurry hinders the drop of the string of tools, a bailer is used to remove the slurry. Water is then added, if needed, and drilling resumes.

Most boreholes drilled in competent formations are drilled "open hole", that is, no casing is used during part or all of the drilling operation. Drilling in competent formations differs from drilling in unconsolidated formations as pipe or well casing (ODEX well casing) must follow the drill bit closely as the hole is advanced to prevent caving and to keep the borehole open.

Use of the cable-tool drilling technique in environmental subsurface investigations is limited because the method is slow. Drilling rates of 20 to 50 feet per day are typical with the average being approximately 30-40 feet per day. Holes much smaller than 6-inches are impractical because of the need for a relatively large, heavy bit. The method does not use drilling muds and allows sampling of groundwater with a drive and bail technique as the hole is advanced in high-yielding formations.

<u>Applications</u>

- Suitable for drilling in all types of geologic formations
- Capable of drilling to almost any depth and diameter range
- Allows for relatively easy installation of monitoring wells and more practicable well development
- Allows collection of excellent samples of geologic materials.

<u>Limitations</u>

- Drilling is relatively slow
- Heaving of unconsolidated materials must be controlled.

Driven Borehole: A borehole can be constructed by driving a solid probe or plugged pipe into the ground. The information obtained by this technique can be either minimal or extensive. Driving through dense materials is often extremely difficult or impossible. Soil samples cannot be collected during this process; however, crude stratigraphic information may be obtained by recording the number of blows per foot of penetration.

Considerably more information can be obtained by driving a penetrometer or a Dutch Cone. Penetration of the soil with a cone forces the soil aside, creating a complex shear failure. The degree of resistance at the cone tip and friction along the side walls yields the geologic logs of the borehole. The borehole created by the penetrometer is usually abandoned; however, occasionally a small-diameter piezometer may be constructed within the borehole. A more detailed account of this method is presented in the section on Cone Penetration Testing (CPT) Standard Operating Procedure (SOP-19).

Applications

- Drilling of boreholes when soil samples are not needed
- Installation of shallow well points at sites with access and work place limitations.

Limitations

- Geologic formations must be conducive to driving method
- Driven boreholes are generally shallow.

4.1.4 Direct-Push Drilling

Direct-push drilling is a method that uses a hydraulic hammer to advance a steel drill stem. Typically, the drill stem consists of threaded lengths of 2-inch to 3-inch outside diameter (OD) steel pipe with a center rod attached to a pointed steel end-plug to keep soils from entering the drill pipe as it is advanced. Sections of drill pipe and center rod are threaded onto the stem as the hole is advanced. The Geoprobe® system is an example of this type of method. Soil samples are collected by removing the center rod and replacing the end-plug with a polyethylene sample tube such as a Macro-Core Sampling Tube System®. The center rod and polyethylene tube are then re-inserted inside the drill casing and the entire assembly is advanced to the desired sampling depth. Once the sampling interval is reached, the sampler is opened and driven an additional two feet into the subsurface allowing soil to enter the tube.

Direct-push drilling is most suitable at sites where physical access restrictions may prevent mobilization of a truck-mounted auger drill rig, or where relatively shallow (<25 feet) soil borings are desired. Under optimal conditions, drilling depths of up to 50 feet may be achieved. Direct-push drilling equipment is typically mounted on the bed of a pick-up truck, a small tractor, or all-terrain vehicle (ATV). This setup enables drilling in limited-access environments, (e.g., inside buildings). Because it is fast and relatively inexpensive, direct-push drilling is often used in screening investigations in relatively fine-grained unconsolidated materials.

<u>Applications & Advantages</u>

- Relatively inexpensive, fast
- No soil cuttings generated
- Usable in limited-access environments
- May be used to install small-diameter monitoring wells or piezometers in unconsolidated formations.

<u>Limitations</u>

- Limited diameter of drill stem limits casing size for monitoring well installations
- Possible cross-contamination of aquifers may occur where annular space is not positively controlled by water, drilling mud, or surface casing
- Smearing of clays may seal off aquifer to be monitored
- Sample integrity in heaving formations may be compromised
- Depending on the size of the drive-rod, coarse-grain and stiff-grained deposits may be impenetrable
- Not suitable for cobbles, boulders or bedrock.

4.2 DRILLING METHODS WITH CIRCULATING FLUIDS

Many drilling techniques use a circulating fluid, such as water, drilling mud, air, a combination of air and water, or even a surfactant to create foam, to aid in the removal of cuttings. Circulation fluids flow from the surface either through the drill pipe, out through the bit, and up the annulus between the borehole wall and the drill pipe (direct rotary) or down the borehole annulus, into the bit, and up the drill pipe (reverse rotary). Generally, the up-hole velocity needed to transport cuttings to the surface is between 100 to 150 feet-per-minute for plain water with no additives, 80 to 120 feet-per-minute for high-grade bentonite drill muds, 50 to 1,000 feet-per-minute for foam drilling, and up to 3,000 feet-per-minute for air with no additives. Additives decrease the required minimum velocity. Excessive velocities can cause erosion of the borehole wall.

The use of circulating fluids may involve the addition of chemicals to the borehole. Drilling mud utilizes bentonite clay or polymers. Additives to air drilling may include surfactants (detergents) and water mist to generate foam. Compressed air may also contain various amounts of hydrocarbon lubricants. Therefore, attention should be given to the circulating fluids and any possible additives that are used when using drilling methods that require circulation fluids.

4.2.1 Rotary Drilling Methods

Rotary drilling methods involve rotation of the drill pipe and the drill bit to advance the borehole. Penetration rates for rotary rigs depend on such mechanical factors as the weight, type, diameter, and condition of the bit, and its speed of rotation; the circulation rate of the drilling fluid and its properties; and the physical characteristics of the geological formation. In rock formations, drillability (defined as depth of penetration per revolution) is directly related to the compressive strength of the rock. The common rotary drilling methods that use circulating fluids to remove the drill cuttings from the borehole are air rotary and mud rotary. The conventional mud-rotary drilling method is not discussed because the addition of mud in environmental drilling is generally considered unacceptable.

Air Rotary Drilling: In air rotary drilling, the circulation fluid is compressed air or a mixture of compressed air, a surfactant, and water mist, which creates a foam. As in conventional mud rotary, the drilling fluid is forced through the rotating drill pipe and bit to flush cuttings to the surface. The drilling fluid flows back to the surface by way of the annulus formed between the outside of the drill pipe and the borehole wall. At the surface, the fluid is directed into a pit or storage container. The up-hole velocity of the air and cuttings should be approximately 3,000 feet-per-minute. This drilling method is primarily used in consolidated formations due to the fact that the rapidly rising cuttings would cause considerable erosion of the borehole wall in unconsolidated formations. With the air rotary drilling method, the circulating fluid is not reused. The functions of the drilling fluid are to:

1. Lift the cuttings from the bottom of the borehole and carry them to the surface.

2. Cool and clean the drill bit.

3. Lubricate the bit, cone bearings, and drill pipe.

Air Rotary Applications & Advantages

- Rapid drilling of semi-consolidated and consolidated rock
- Good quality/reliable formation samples
- Equipment is generally available
- Allows easy and quick identification of lithologic changes
- Allows identification of most water bearing zones
- Allows estimation of yields in strong water-producing zones with short "down time."

Air Rotary Limitations

- Surface casing frequently required to protect top of hole
- Drilling restricted to semi-consolidated and consolidated formations
- Samples are reliable, but occur as small particles that are difficult to interpret
- Drying effect of air may mask lower yield water producing zones or identification of the water table
- Air stream requires contaminant filtration
- Air may modify chemical or biological conditions; recovery time uncertain.

4.2.2 Air Rotary Casing Hammer (Drill and Drive)

This method combines percussion and air rotary drilling methods to drill in unconsolidated formations. The borehole is drilled using the air rotary drilling method. Casing or ODEX follows closely behind the rotary bit to prevent the erosion of the borehole wall. The drill bit is usually extended approximately one foot below the bottom of the casing that acts as temporary casing.

Applications & Advantages

- Rapid drilling of unconsolidated sands, silts, and clays

- Drilling in alluvial materials (including boulder formations)
- Casing supports borehole thereby maintaining borehole integrity and minimizing inter-aquifer cross contamination
- Eliminates circulation problems common with direct mud rotary method
- Good formation samples for stratigraphic evaluation
- Minimal formation damage as casing is pulled back.

<u>Limitations</u>

- Thin, low pressure water bearing zones easily overlooked if drilling not stopped at appropriate places to observe whether or not water levels are recovering
- Samples pulverized as in all rotary drilling
- Air may modify chemical or biological conditions
- Difficult to obtain soil samples for chemical analysis.

4.2.3 Center Stem Recovery Rotary Drilling (Reverse Circulation)

In reverse circulation (RC) drilling, the circulating fluid (water) flows from the surface down the borehole annulus outside the drill pipe, into the drill bit, and up the inside of the drill pipe to the ground surface. The fluid carries the cuttings to the surface and discharges them into a settling pit or tank. Reverse circulation is particularly well suited to drilling large diameter boreholes in soft, unconsolidated formations, and in situations where the erosive velocity of conventional rotary circulation would be detrimental to the borehole wall. Drilling is accomplished typically with water, without the use of additives.

A dependable water supply is required to maintain sufficient drilling fluid in the borehole, thereby maintaining sufficient hydrostatic head on the borehole walls to prevent sloughing. Reverse circulation has limited application in environmental subsurface investigations. Typical borehole diameters range from 8 to 36 inches; however, 60-inch-diameter boreholes are not uncommon.

<u>Applications & Advantages</u>

- Large capacity production wells

- Nested wells
- Normally does not use drilling muds (little if any mud cake is formed on the wall of the borehole
- Drills best in unconsolidated sands, silts, and clays.

Limitations

- Requires large and dependable source of water during drilling and well installation
- Cobbles and bedrock are difficult to drill.

4.2.4 Dual-Tube Rotary

Dual-tube rotary is an exploratory drilling technique utilizing two concentric drill pipes which consist of an inner and an outer pipe. Both drill pipes are rotated during drilling.

The outside diameter of the outer drill pipe is typically 4.5 inches. The diameter of the borehole is approximately 5 inches. Compressed air is forced between the two drill pipes and is directed to the inner pipe at the bit. The air then flows up the inner pipe and cuttings are carried to the surface at a velocity of approximately 3,000 feet per minute. This drilling method provides for identification of the subsurface lithology and the locations of aquifers in deep boreholes.

It is very difficult to obtain undisturbed soil samples for chemical or geotechnical analyses using this method; however, groundwater samples can be obtained as aquifers are encountered. Geophysical logs can be obtained if the borehole is filled with drilling mud as the drill pipe is removed. Depths of 1,000 feet are not uncommon for this drilling method and typically, the more consolidated the formation, the more suitable the method. Unconsolidated formations may cause more drag or friction on the outside of the rotating drill pipe.

Applications & Advantages

- Used mostly for exploratory boreholes
- Allows rapid extraction of drill cuttings from the borehole
- Drill cuttings are representative of formation
- Very rapid penetration rate in all formations
- Able to collect groundwater samples as aquifers are encountered.

Limitations

- Equipment usually not readily available
- Inability to obtain undisturbed soil samples for chemical analysis
- Borehole typically small in diameter (5 inches).

4.2.5 Dual-Tube Percussion Drilling

Dual-tube percussion drilling is very similar to dual-tube rotary, with the exception that the two drive pipes do not rotate during drilling. The two concentric drive pipes are driven into the ground with a percussion hammer. The hammer is similar to the mechanisms mounted on pile drivers. The typical outside diameter of the outer drive pipe is 7 to 12 inches. The typical inside diameter of the inner pipe, where well materials are normally inserted, is 4.25 to 8 inches. This drilling system is also a center stem recovery system and is used primarily in hazardous waste investigations. It is rapid and effective to depths of about 250 feet.

The outer pipe effectively seals off the formation while drilling, reducing the chance of cross contamination. Air is pumped between the annulus of the two pipes to the bit where it is deflected upward into the inner pipe. Cuttings are transported to the surface through the inner pipe.

In general, three systems are available: 7-inch OD/4.25-inch ID, 9-inch OD/6-inch ID, and 12-inch OD/8-inch ID. A 2-inch-diameter monitoring well can be constructed in the 7-inch system, a 4-inch-diameter monitoring well can be constructed in the 9-inch system, and a 5- or 6-inch-diameter monitoring well can be constructed in the 12-inch system.

Applications

- Very rapid drilling through both unconsolidated and consolidated formations
- Allows continuous sampling for lithologic logging in all types of formations
- Representative samples can be obtained with minimal risk of contamination of sample and/or water bearing zone
- In stable formations, wells with diameters as large as 6 inches can be installed in open hole completions

- Soil samples can be easily obtained for chemical analysis.

Limitations

- In unstable formations wells are limited to approximately 4 inches
- Air may modify chemical or biological conditions; recovery time is uncertain
- Not suitable for cobbles, boulders, or bedrock.

4.2.6 Rock Coring

Rock coring is a valuable method of obtaining undisturbed samples of bedrock. Rock coring utilizes a diamond or carbide hollow drill bit driven by solid rods. Unlike rotary or cable-tool methods, which grind or pulverize solid rock into small particles, rock cores allow bedding, structures, fossils, and fractures or other types of secondary porosity to be examined directly. Cores can also be submitted for laboratory testing of engineering qualities, and for analysis of porosity and permeability.

The most conventional method of coring is by attaching a core barrel and coring bit to a rotary drill string. Core barrels generally come in 5- or 20-foot lengths, and can be joined together to allow continuous cores up to 60 feet long to be collected during a single run. A split inner barrel is wrapped with strapping tape at intervals to prevent the inner barrel from opening during coring. The inner barrel is inserted in the core barrel and the bit is attached. The ring-shaped face of the coring bit is typically a diamond-impregnated steel alloy. Many different bit styles and configurations are available; the most effective bit for coring a particular lithology is dependent on the rock's physical characteristics. Bit suppliers usually have knowledge of the type of bit most appropriate for the lithologies in their region, and are a good resource in planning a coring program.

Once the core barrel has been assembled, it is lowered downhole on the drill string and rotated. Drilling fluid is injected in the annular space between the inner split barrel and the core barrel, and exits through holes in the face of the coring bit. As with conventional rotary drilling, the drilling fluid cools and lubricates the bit, and carries cuttings to the surface from the annular space cut by the bit between the drillhole wall and the core.

When the desired interval has been cored, the core barrel is tripped out of the hole. Steel core retainers and friction between the core and the inside of the inner barrel keep the rock core from dropping out of the core barrel as it is tripped out. In conventional drilling and coring, the drill string is removed in 10 to 20-foot joints at a time, placed vertically on the rig floor, and attached at the crown of the mast in "fingerboards". This reduces the amount of time to break and make connections.

When the core barrel is out of the hole, the drill crew removes the split inner barrel and places it on the catwalk or on racks. The site geologist usually cuts the strapping tape and opens the split barrel to examine the core. Depending on the type of rock and the drilling fluid used, the rock core may need to be cleaned with a brush and clean water before it can be logged. A measuring tape is placed along the length of the core, to facilitate the logging process. Once logging is complete, the core is broken into 3-foot lengths and placed in plastic or waxed cardboard core boxes. The boxes are marked as to hole location, depth interval, date, and other pertinent information. Cores are placed in the box from left to right and top to bottom, such as one reads a book. Thus, the top of the core is in the upper left corner of the core box, and the bottom end of the core is in the lower right corner of the box.

<u>Applications & Advantages</u>

- Cores provide undisturbed samples of bedrock
- Cores can be used for testing engineering characteristics
- Cores can be used to analyze porosity and permeability.

<u>Limitations</u>

- Coring is very expensive and time-consuming compared to rotary drilling
- Extensively fractured or soft formations can result in incomplete core recovery
- To avoid missing an important formational contact, many geologists will core excessive lengths, incurring additional cost. Knowledge of local stratigraphy and structural conditions can reduce the core interval and minimize costs.

4.3 DRILLING IN ARTESIAN CONDITIONS

When drilling in artesian conditions or in an area where artesian conditions are suspected (e.g., a nearby monitoring well exhibits artesian pressure), special precautions must be taken to prevent the upward movement of artesian waters within the borehole. In accordance with the *State of Utah Water Well Handbook, based on Administrative Rules for Water Well Drillers* (Utah Division of Water Rights, 2002), the driller will not move the drilling rig from the site until leakage is completely stopped. The following sections provide procedures for drilling and monitoring well installation in areas where known artesian conditions exist. This SOP will be used on a case by case basis. Deviations from the SOP must have prior written approval by project stakeholders. In the event of an emergency, verbal consent from project stakeholders should be sought, followed by written documentation.

Drilling Procedures/Techniques: When drilling in areas where artesian conditions are known to exist, only drilling methods using a casing advancement technology will be permitted (e.g., reverse circulation air rotary system with percussion hammer, casing advanced air rotary drilling systems, cable-tool drilling, sonic, or ODEX drilling methods). Air rotary systems will be capable of drilling with supplementary water, or water with approved additives as a circulation medium. Compressed air will be filtered by an in-line filter system to prevent compressor-oil contamination of the circulation system and borehole. The filter will be capable of ensuring 99.999 percent removal of any oil in the compressed air. Filter samples ("knock-outs") will be collected and retained for potential analysis. Drilling rod joint lubricant will be vegetable-based and the use of the lubricant will be minimized. Documentation of drill rig compliance and the proposed lubricant will be provided to EMR for approval prior to drilling. During air rotary drilling, cuttings will be collected in a cyclone. Dispersion of particulates will be minimized. All cuttings and fluids will be handled and contained appropriately to prevent their release to the environment. Source water used for circulation will be analyzed for contaminants of potential concern.

Soil Sampling and Sediment Logging: Soil samples for logging, geotechnical, and analytical purposes will be collected from boreholes in accordance with project-specific field sampling plans. During soil sample collection, care and diligence should be given so that the sample can be collected in a manner that causes minimal disturbance to the aquifer materials. A maximum water head (approved source water only) will be maintained inside the casing at all times to stabilize formation material during soil sampling. However, if flowing sands are encountered, no soil samples will be collected. A detailed log of the volume of source water that has been added to the borehole will be maintained. Well development is to evacuate a minimum of five times the volume of water added to the borehole.

Dense drilling mud, used to stabilize the formation during drilling and sampling, may be permitted, but only when flowing sands present a significant problem, and stabilization with water has failed. If flowing sands are anticipated prior to drilling or encountered during drilling operations. It is very important to recognize site-specific conditions and potential problems when drilling and installing wells in artesian conditions. Sound judgement from the site geologist is expected. Therefore, the site geologist must be, at a minimum, a mid-level geologist/hydrogeologist and have at a minimum of five years of well installation experience, and must have experience in installing wells in confined/artesian conditions. In addition, the drilling subcontractor will also provide a drill rig operator with more than five years' operating experience, and the operator also must have experience in installing wells in confined/artesian conditions.

Borehole Diameter: Borehole diameter will be no less than 8-inches in diameter for 2.5-inch wells and smaller; no less than 10-inches in diameter for wells 3 to 4 inches in diameter; and no less than 12-inches in diameter for 6-inch diameter wells.

4.3.1 Well Completions in Artesian Conditions

Filter Pack: The sand pack will extend from the base of the well screen to a minimum of 5 feet above the well screen, provided that the filter pack does not extend upward into the confining sedimentary unit. The sand pack will consist of 10-20 sieve size silica sand. A minimum of 5-feet of sand will be maintained inside the drill casing at all times during sand pack installation. Adding approved source water to the borehole during sand pack installation is permitted and recommended to stabilize the borehole. If necessary, sand may be flushed through a tremmie pipe using approved source water as the carrier fluid.

Well Screen: The well screens will be sized based on intended use of the well and 10-20 sieve size silica sand will be used for the filter pack.

Well Seal: The well seal will be a minimum of 5-feet thick and will consist of coated bentonite pellets. The well seal will extend from the top of the filter pack upward through the entire thickness of the confining sedimentary unit. Coated bentonite pellets will be maintained inside the drill casing during seal installation. Adding approved source water to the borehole during seal installation is permitted and recommended to stabilize the borehole.

Grout: Grout will consist of a mixture of Aqua-guard® Gel and Bar Bariod®. The grout mixture will contain 1-½ sacks Aqua-guard® Gel and 100 lbs. Bar Bariod® added to 10 gallons of water. The borehole will be grouted from the bottom up using a pump and tremmie pipe. A grout pump capable of pumping this thick, heavy mixture will be required. Grout will not be added from the surface and allowed to fall though the drill casing. The grout will extend from the top of the bentonite seal to 10 feet below the ground surface. Dense concrete will be used from 10 feet below the ground surface, to the ground surface, to hold the grout in place and to prevent the grout from heaving.

Surface Completion: In the event that the well is completed under artesian conditions and is a flowing well, the well top will be completed in one of two ways:

1. The top of casing may be fitted with a gate valve that will allow the flow to be controlled as necessary. The well head assembly will also include a pressure gauge capable of measuring the hydraulic head in the well to assist with static head measurements, and a sampling port for groundwater sample collection. The monitoring well vault will be designed to allow sufficient room inside the vault to accommodate the well head assembly.
2. The well may be completed above ground allowing sufficient stick-up to accommodate static heads above ground surface. This completion method may, however, not be practicable in cases where static groundwater levels are likely to exceed 3 - 4 feet above ground surface, or where lease agreements stipulate that the well be completed as flush mount.

4.4 BOREHOLE ABANDONMENT PROCEDURES

Subsurface borings will be abandoned according to the procedures outlined in SOP-4.

4.5 BOREHOLE REFUSAL CRITERIA

Certain types of subsurface conditions, (e.g., debris, boulders, and gravel layers), may halt the advancement of soil borings depending on the drilling method in use. In such cases, the borehole will be abandoned and a new boring will be performed if needed at a location that will fulfill the project-specific goals. The new soil boring location may be subject to clearance requirements by Blue Stakes. The drilling subcontractor has the final authority in determining when refusal has been encountered.

5.0 CONSIDERATIONS FOR SELECTION OF DRILLING METHODS

Each project or drilling site has its own characteristics that pose unique challenges in the selection of drilling methods. Prior to selecting a drilling method, several factors will be considered. The major factors addressed in this section include the objectives of the drilling program, site conditions, wastes generated, and client preferences. Other factors include drilling costs, availability of trained crews and appropriate equipment, and project schedule requirements. It is important to recognize that it may be very difficult to fulfill all of the drilling (and sampling) objectives with a single drilling method. The drilling method selected may compromise some of the objectives of the drilling program.

5.1 DRILLING OBJECTIVES

The primary consideration in the process of selecting any drilling method is the objective(s) of the drilling/sampling program. It is common to have more than one objective for the drilling/sampling program and it may be difficult to satisfy all of the objectives.

If sample collection (soil / rock, or groundwater) is the objective, the selected method will be capable of collecting, in an appropriate and approved manner, the necessary samples. Additionally, the contaminants of concern may have an influence on the selection of the drilling and sampling method.

If the objective of the drilling program is to install vapor or groundwater extraction wells, the selected method will be suitable for the installation of the designed well. It is important to not only consider the physical limitations of a particular drilling technique (i.e., depth and diameter), but to also examine the consequences of the drilling method with respect to the drilling objective (e.g., smearing of the borehole walls may render wells ineffective or inefficient).

Similarly, if one of the objectives of the drilling program is to identify the different water-bearing zones, the drilling method will be able to accomplish this task.

5.2 SITE CONDITIONS

Site conditions can limit the drilling methods available for a particular program. Site conditions to be considered include ease of access and applicable requirements, as well as surface and subsurface conditions.

Surface Conditions: Surface conditions can affect access to the site and the amount of available workspace (horizontal, vertical or overhead space). These in turn can affect the selection of a particular method or type of drill rig. Limited access and work space may require smaller or remotely powered drill rigs. The site terrain is also an important factor in choosing the drilling method as it may prove to be expensive and difficult to mobilize large and/or heavy equipment over rugged terrain. For such sites, drill rigs (typically hollow-stem auger) are usually mounted on all-terrain equipment.

In addition to access and workspace, the work environment will also be considered. This includes both weather conditions and other site activities. Extremely hot or cold climates may require use of special drilling equipment or methods. Sites where explosive atmospheres are likely to exist may require special consideration. All site activities will be considered as they may impact the selection of the drilling method.

Subsurface Conditions: The subsurface stratigraphy of a site is a fundamental consideration when selecting a particular drilling method. The drilling equipment selected will be capable of effectively and economically penetrating the strata at the site to meet the project data quality objectives. Particular stratigraphy which may pose problems for certain drilling methods include tight clayey soils, swelling clays, flowing sands, caliche, gravels, cobbles, lost circulation zones, and bedrock.

In addition to stratigraphy, the site hydrology will also be considered. If multiple water-bearing zones are expected, a conductor casing may be needed to seal off shallow water-bearing zones to prevent potential cross contamination. The need for conductor casings may influence the selection of a particular drilling method. Drilling of wells that penetrate deep aquifers may also influence the selection of a suitable drilling method.

5.3 WASTE GENERATION

Drilling operations typically generate significant volumes of waste that must be handled, stored, and eventually disposed. This is of particular concern when drilling into contaminated or hazardous subsurface environments. The type and volume of wastes generated during drilling differs for different drilling methods. The different handling and disposal requirements of generated wastes can greatly affect project costs. The different drilling methods may also require removal of vastly different volumes of groundwater to fully develop the well.

6.0 REFERENCES

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STANDARD OPERATING PROCEDURE 2

SOIL AND ROCK CLASSIFICATION

STANDARD OPERATING PROCEDURE 2

SOIL CLASSIFICATION

TABLE OF CONTENTS

1.0 INTRODUCTION

This standard operating procedure (SOP) is intended for use as a guide for soil logging procedures at sites requiring subsurface investigation. The SOP employs the Unified Soil Classification System (USCS) and the ASTM Standard D 2488 - 90 Standard Practice for Description and Identification of Soils (Visual-Manual Procedure; ASTM, 1990). In addition, this SOP also employs the *Unified States Bureau of Reclamation Chapter 4 Classification of Rocks and Descriptions of Physical Properties of Rocks;* included at the end of the SOP. A thorough working knowledge of this SOP is critical for field personnel to standardize logging procedures and to enable subsequent correlation between borings at a site, allowing for accurate site characterization.

The information described in this SOP is summarized on the USCS chart in Attachment A. Laminated copies of this chart shall be available for all field personnel. Other field references may also be used according to personal preference. However, such references shall be based on the USCS.

2.0 DEFINITIONS

Use of the USCS requires familiarity with the grain size ranges that define a particular type of soil, as well as several other physical characteristics. The grain size definitions and physical characteristics upon which soil descriptions are based are presented below.

2.1 GRAIN SIZES

USCS grain sizes are based on U.S. standard sieve sizes, which are defined as follows:

- Standard sieves with larger openings are named according to the size of the openings in the sieve mesh. For example, a "No.3" sieve contains 3 openings per square inch.
- Standard sieves with smaller openings are given numbered designations that indicate the number of openings per square inch. For example, a "No. 4" sieve contains 4 openings per square inch.

The following grain size definitions are paraphrased from the ASTM Standard D 2488 - 90. Field personnel shall familiarize themselves with the grain size definitions and refer to the appropriate field guide for a visual reference.

Boulders: Particles of rock that will not pass a 12-in. (300-millimeter [mm]) square opening.

Cobbles: Particles of rock that will pass a 12-in. (300-mm) square opening and be retained on a 3-in. or 75 mm sieve.

Gravel: Particles of rock that will pass a 3-in (75-mm) sieve and be retained on a No. 4 (4.75-mm) sieve with the following subdivisions:

Coarse Gravel: Passes a 3-in. (75-mm) sieve and is retained on a 3/4-in. (19-mm) sieve

Fine Gravel: Passes a 3/4-in. (19-mm) sieve and is retained on a No. 4 (0.19 in. or 4.75-mm) sieve

Sand: Particles of rock that will pass a No. 4 (0.19 in. or 4.75-mm) sieve and be retained on a No. 200 (0.0029 in. or 75-micrometer [µm]) sieve with the following subdivisions:

Coarse Sand: Passes a No. 4 (0.19 in. or 4.75-mm) sieve and is retained on a No. 10 (0.079 in. or 2-mm) sieve

Medium Sand: Passes a No. 10 (0.079 in. or 2-mm) sieve and is retained on a No. 40 (0.017 in. or 425-µm) sieve

Fine Sand: Passes a No. 40 (0.017 in. or 425-µm) sieve and is retained on a No. 200 (0.0029 in. or 75-µm) sieve

Silt: Soil passing a No. 200 (0.0029 in. or 75-µm) sieve that is non-plastic or very slightly plastic, and that exhibits little or no strength when air-dried. Individual silt particles are not visible to the naked eye.

Clay: Soil passing a No. 200 (0.0029 in. or 75-µm) sieve that can be made to exhibit plasticity within a range of moisture contents, and that exhibits considerable strength when air-dried. Individual clay particles are not visible to the naked eye.

2.2 PHYSICAL CHARACTERISTICS

The physical characteristics described below are used in the USCS classification for fine-grained soils. Physical characteristics of coarse-grained soils and consolidated rock are presented in Section 4.2. A brief definition of each physical characteristic is presented including a description and criteria. However, with the exception of plasticity, the criteria for the field tests are generally too time-consuming to perform regularly in the field. A determination of the type of fine-grained soil present in the sample can generally be made on the basis of plasticity, as described in Section 4.1.2.

Dry Strength: The Dry Strength is described as the ease with which a dry lump of soil crushes between the fingers.

Description	Criteria
None:	The dry specimen crumbles into powder with mere pressure of handling.
Low:	The dry specimen crumbles into powder with some finger pressure.
Medium:	The dry specimen breaks into pieces or crumbles with considerable finger pressure.
High:	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface.

Very High:	The dry specimen cannot be broken between the thumb and a hard surface.

Dilatancy Reaction: Dilatancy reaction is described at the speed with which water appears in a moist part of soil when shaken in the hand, and disappears while squeezing.

Description	Criteria
None:	No visible change in the specimen.
Slow:	Water appears slowly on the surface of the specimen during shaking and does not disappear or disappears slowly upon squeezing.
Rapid:	Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing.

Toughness: Toughness is described as the strength of a soil, moistened near its plastic limit, when rolled into a 1/8-in. diameter thread.

Description	Criteria
Low:	Only slight pressure is required to roll the thread near the plastic limit. The thread and the lump are weak and soft.
Medium:	Medium pressure is required to roll the thread to near the plastic limit. The thread and the lump have medium stiffness.

High:	Considerable pressure is required to roll the thread to near the plastic limit. The thread and the lump have very high stiffness.

Plasticity: Plasticity is described as the extent to which a soil may be rolled into a 1/8 in. thread, and re-rolled when drier than the plastic limit.

Description	Criteria
Nonplastic:	A 1/8-in. (3-mm) thread cannot be rolled at any water content.
Low:	The thread can barely be rolled and the lump cannot be formed when drier than the plastic limit.
Medium:	The thread is easy to roll and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit.
High:	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rerolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit.

3.0 RESPONSIBILITIES

This section presents a brief definition of field roles, and the responsibilities generally associated with them. This list is not intended to be comprehensive and often additional personnel may be involved. Project team member information shall be included in project-specific plans (e.g., work plan, field sampling plan, quality assurance plan, etc.), and field personnel shall always consult the appropriate documents to determine project-specific roles and responsibilities. In addition, one person may serve in more than one role on any given project.

MWH Project Manager: Defines objectives of fieldwork. Prepares drilling and sampling plans with input from the Project Hydrogeologist/Field Team Leader. Oversees and prepares subcontracts.

MWH Field Team Leader (FTL) and/or Project Hydrogeologist, Geologist, or Engineer: Implements field program. Records and reviews boring logs. Supervises drilling subcontractor. Prepares daily logs of field activities.

4.0 SOIL LOGGING PROCEDURES

The following aspects of a project shall be considered before sampling and soil logging commences. This information is generally summarized in a project-specific work plan or field sampling plan, which shall be thoroughly reviewed by all field personnel prior to the initiation of work.

- Purpose of the soil logging (e.g., initial investigation, subsequent investigation, remediation, etc);
- Known or anticipated hydrogeologic setting including stratigraphy (i.e., consolidated/unconsolidated, depositional environment, presence of fill material, etc.), physical characteristics of the aquifer (porosity/permeability), type of aquifer (confined/unconfined), recharge/discharge conditions, aquifer thickness and groundwater/surface water interrelationships;
- Drilling conditions
- Previous soil boring or borehole geophysical logs (these should be carried to the field for reference)
- Soil sampling and geotechnical testing program
- Characteristics of potential chemical release(s) (i.e., chemistry, density, viscosity, reactivity, and concentration, etc.)
- Health and Safety requirements
- Regulatory requirements

The procedures used to determine the correct soil sample classification are described below.

4.1 FIELD CLASSIFICATION OF SOILS

The following soil classification procedures are based on the ASTM Standard D 2488 - 00 for visual-manual identification of soils (ASTM, 2000). When identifying soils, the proper USCS soil group name is given, followed by the group symbol. For clarity, the group symbol shall be placed in parentheses after the written soil group name. Alternatively, a separate column may be designated for the group symbol.

Soil identification using the visual-manual procedures is based on naming the portion of the soil sample that will pass a 3-in. (75-mm) sieve. Therefore, before classifying a soil, any particles larger than 3 inches (cobbles and boulders) shall be removed, if possible. The percentage of cobbles and boulders shall be estimated and recorded.

Using the remaining soil, the next step of the procedure is to estimate the percentages, by dry weight, of the gravel, sand, and fine fractions (particles passing a No. 200 sieve). The percentages shall be estimated to the closest 5 percent. In general, the soil is *fine-grained* (e.g., silt or clay) if it contains 50 percent or more fines, and *coarse-grained* (e.g., sand or gravel) if it contains less than 50 percent fines. If one of the components is present but estimated to be less than 5 percent, its presence is indicated by the term *trace*. For example, 'trace of fines' shall be added as additional information following the formal USCS soil description.

Procedure for Identifying Coarse-Grained Soils: If the sample has been determined to contain less than 50 percent fines, the soil may be classified as either *gravel* (if the percentage of gravel is estimated to be more than the percentage of sand), or *sand* (if the percentage of gravel is estimated to be equal to or less than the percentage of sand).

If the soil is predominantly sand or gravel but contains an estimated 15 percent or more of the other coarse-grained constituent, the words "with gravel" or "with sand" shall be added to the group name. For example: "gravel with sand (GP)." If the sample contains any cobbles or boulders, the words "with cobbles” or "with cobbles and boulders" shall be added to group name. For example: "silty gravel with cobbles (GM)".

5 Percent or Less Fines: The soil is a 'clean gravel' or 'clean sand' if the percentage of fines is estimated to be 5 percent or less. 'Clean' is not a formal USCS name, but rather a general descriptor for implying little to no fines. Clean sands and gravels are given the USCS designation as either *well graded* or *poorly graded*, as described below.

The soil sample is *well-graded gravel* (GW), or *well-graded sand* (SW), if it has a wide distribution of particle sizes and substantial amounts of the intermediate particle sizes. On the other hand, the soil sample is a *poorly-graded gravel* (GP) or *poorly-graded sand* (SP) if it consists predominantly of one grain size (uniformly graded), or has a distribution of sizes with some intermediate sizes obviously missing (gap- or skip-graded).

<u>NOTE:</u> When using the USCS, keep in mind the differences between grading and sorting. The term grading is used to indicate the size class of particles contained in the sample, while sorting refers to the range of the particle sizes on either side of the average particle size. For example, poorly-graded sand containing predominantly one grain size would be considered well-sorted, and vice-versa. One notable exception to this general rule is a skip-graded (bi-modally distributed) sample: sand containing two distinct grain sizes would be considered both poorly-sorted and poorly-graded. The USCS uses only the *GRADING* descriptor in soil naming, not the sorting descriptor.

15 Percent Fines: If the percentage of fines is estimated to be 15 percent or more, the soil may be classified as *silty or clayey gravel* or *silty or clayey sand*. For example, a soil can be identified as *clayey gravel* (GC) or *clayey sand* (SC) if the fines are clayey, or as *silty gravel* (GM) or *silty sand* (SM) if the fines are silty. The coarse-grained descriptor "poorly-graded" or "well-graded" is not included in the soil name, but rather, shall be included as additional information following the formal USCS soil description.

>5 Percent but <15 Percent Fines: If the soil is estimated to contain greater than 5 percent and less than 15 percent fines, the soil sample shall be designated with a dual identification using two group symbols. The first group symbol shall correspond to the clean gravel or sand portion of the sample (i.e., GW, GP, SW, SP) and the second symbol shall correspond to the clayey/silty gravel or sand portion (i.e., GC, GM, SC, SM). The group name shall correspond to the first group symbol, and include the words "poorly-graded" or "well-graded", plus the words "with clay" or "with silt" to indicate the character of the fines. For example, "poorly-graded gravel with silt" would have the symbol GM, and “poorly graded gravels or gravel-sand mixtures” would have the symbol GP.

Procedure for Identifying Fine-Grained Soils: The USCS classifies inorganic, fine-grained soils according to their degree of plasticity and other physical characteristics defined in Section 2.2 and Tables 9-1 through 9-4 (i.e., soil sample with no or low plasticity is indicated with an "L"; and soil sample with high plasticity is indicated with an "H"). As indicated in Section 2.2, the field tests used to determine dry strength, dilatancy, and toughness are generally too time-consuming to be performed on a routine basis. However, the field test for plasticity can be easily performed. While field personnel shall be familiar with the definitions of the physical characteristics and concepts of the field tests, field classifications shall generally be based primarily on plasticity. NOTE: if precise engineering properties are necessary for the project (e.g., construction or modeling) geotechnical samples shall be collected for laboratory testing. The results of the laboratory tests shall be compared to the field logging results. Characteristic physical properties of fine-grained soils are listed below.

Silt (ML): the soil has no to low dry strength, slow to rapid dilatancy, and low toughness and plasticity, or is nonplastic.

Lean clay (CL): inorganic clay soil with medium to high dry strength, no or slow dilatancy, medium toughness, and slightly plastic.

Organic soil (OL or OH): the soil contains enough organic particles to influence the soil properties. Organic soils usually have a dark brown to black color and may have an organic odor. Often, organic soils will change color, for example, from black to brown, when exposed to the air. Organic soils normally will not have a high toughness or plasticity.

Elastic silt (MH): the soil has low to medium dry strength, no to slow dilatancy, and low to medium toughness and plasticity; will air dry more quickly than lean clay and have a smooth, silky feel when dry.

Fat clay (CH): soil has high to very high dry strength, no dilatancy, and high toughness and plasticity.

Other Modifiers for use with Fine-Grained Soils:

15 Percent to 25 Percent Coarse-Grained Material: If the soil is estimated to have 15 percent to 25 percent sand or gravel, or both, the words "with sand" or "with gravel" (whichever is predominant) shall be added to the group name. For example: "lean clay with sand (CL)" or "silt with gravel (ML)". If the percentage of sand is equal to the percentage of gravel, use "with sand".

30 Percent Coarse-Grained Material: If the soil is estimated to have 30 percent or more sand or gravel, or both, the words "sandy" or "gravelly" shall be added to the group name. Add the word "sandy" if there appears to be the same or more sand than gravel. Add the word "gravelly" if there appears to be more gravel than sand. For example: "sandy silt (ML)", or "gravelly fat clay (CH)".

Procedure for Identifying Borderline Soils: To indicate that the soil may fall into one of two possible basic groups, a borderline symbol may be used with the two symbols separated by a slash. For example, a soil containing an estimated 50 percent silt and 50 percent fine-grained sand may be assigned a borderline symbol "SM/ML". Borderline symbols shall not be used indiscriminately. Every effort shall be made to first place the soil into a single group and then to estimate percentages following the USCS soil description.

4.2 DESCRIPTIVE INFORMATION FOR SOILS

After the soil name and symbol are assigned, the soil color, consistency/density, and moisture content shall be described <u>in that order</u>. Other information is presented later in the description, as applicable.

Color: Color is an important property in identifying both inorganic and organic soils, and may also be useful in identifying materials of similar geologic or depositional origin in a given location. Munsell Soil Color Charts or Rock Charts shall be used.

When using Munsell Soil Color Charts, use the appropriate color charts to assign the applicable color name and Munsell symbol to a wet soil sample (colors change as moisture content changes, and all color descriptions shall be made on wet soil for consistency). The ability to detect minor color differences varies among people, and the chance of finding a perfect color match in the charts is rare. Keeping this in mind shall help field personnel avoid spending unnecessary time and effort going through the chart pages. In addition, attempts to describe soils in detail beyond the reasonable accuracy of field observations may result in less accurate soil descriptions than would be achieved by simple expression of the dominant colors (Munsell Soil Color Chart, 1992). All soil color information shall be recorded in the field logbook or field forms.

It should be noted that soil color may also be impacted by contamination. To the extent possible, information pertaining to color impacted by such factors shall also be recorded on the boring logs.

Consistency/Density: Consistency is used to describe fine grained soils (silt and clay) and density is used to describe coarse grained (sand and gravel). Consistency and density can be described based on the blows per foot using a 140-pound hammer dropped 30" or by completing field tests. This and other pertinent information shall be clearly indicated in the field log book on the soil boring-log.

Criteria for Describing Consistency by field test

Consistency (Silt and Clay)	**Blows/ft***	**Thumb Penetration**
Term	2.0" ID	
Very soft:	0-2	Easily penetrated several inches by thumb.
Soft:	2-4	Easily penetrated 1in. (25 mm) by thumb. Molded with light finger pressure.
Medium stiff:	4-9	Can be penetrated ¼ in. (6 mm) by thumb with moderate effort. Molded with strong finger pressure.
Stiff:	9-17	Indented about penetrated ¼ in. (6 mm) by thumb but penetrated only with great effort.
Very stiff:	17-39	Readily indented by thumbnail.
Hard:	39-78	Indented with difficulty by thumbnail.
Very hard:	>78	Unable to indent with thumbnail.

Density (Sand and Gravel) Blows/ft*	**Blows/ft***	**Thumb Penetration**

Term	2.0" ID	
Very loose:	0-5	Easily penetrated with thumbnail
Loose:	5-12	Easily penetrated with finger pressure
Medium dense:	12-37	Penetrated by strong finger pressure.
Dense:	37-60	Penetrated only slightly by strong finger pressure.
Very dense:	>60	Penetrated only slightly by very strong finger pressure.

Moisture: Moisture condition of the soil shall be described as dry (absence of moisture, dusty, dry to the touch), moist (damp but no visible water), or wet (visible free water, saturated).

Angularity: Describe the angularity of the sand (coarse sizes only), gravel, cobbles, and boulders, as angular, sub-angular, sub-rounded, or rounded in accordance with the following criteria:

Angular: Particles have sharp edges and relatively planar sides with unpolished surfaces

Sub-angular: Particles are similar to angular description but have rounded edges

Sub-rounded: Particles have nearly planar sides but have well-rounded corners and edges

Rounded: Particles have smoothly curved sides and no edges.

A range of angularity may be stated, such as "sub-rounded to rounded."

Grain Size: The maximum particle size found in the sample shall be described in accordance with the following information:

Sand Size:	If the maximum particle size is a sand size, describe as fine, medium, or coarse. (See Section 2 for sand size definitions.)
Gravel Size:	If the maximum particle size is a gravel size, describe the diameter of the maximum particle size in inches.
Cobble or Boulder Size:	If the maximum particle size is a cobble or boulder size, describe the maximum dimension of the largest particle.

For gravel and sand components, describe the range of particle sizes within each component; for example, "about 20 percent fine to coarse gravel, about 40 percent fine to coarse sand".

Odor: Due to health and safety concerns, NEVER intentionally smell the soil. This could result in exposure to volatile contaminants that may be present in the soil. If, however, an odor is noticed, it shall be described accordingly. Soils containing a significant amount of organic material usually have a distinctive odor of decaying vegetation (sometimes a hydrogen sulfide or "rotten egg" smell). If the odor is determined to be due to the likely presence of petroleum-based products or other chemicals, it shall be described as such. Organic vapor readings from organic vapor monitoring equipment shall be noted on the field boring-log. The project-specific health and safety plan shall then be consulted for specific information and guidelines on the appropriate level of protection necessary for the continuation of field activities at the site.

Cementation: Describe the cementation of intact coarse-grained soils as weak, moderate, or strong, in accordance with the following criteria:

Weak:	Crumbles or breaks with handling or little finger pressure
Moderate:	Crumbles or breaks with considerable finger pressure
Strong:	Will not crumble or break with finger pressure.

The presence of calcium or magnesium carbonates may be confirmed on the basis of effervescence with dilute hydrochloric acid (HCl). Proper health and safety precautions shall be followed when mixing, handling, storing, or transporting HCl.

Structure: Structure of intact soils shall be described in accordance with the criteria in Table 9-7.

Lithology/Mineralogy: Describe the lithology (rock or mineral type) of the sand, gravel, cobbles, and boulders, if possible. It may be difficult to determine the lithology of fine and medium-grained sand or particles that have undergone alteration.

Additional Comments: Additional comments may include the presence of roots or other vegetation, fossils or organic debris, staining, mottling, iron and magnesium oxidation, difficult drilling, and caving or sloughing of the borehole walls. Also, when drilling in an area known or suspected to contain imported fill material, every effort shall be made to identify the contact between fill and native soils. If a soil is suspected to be fill, this shall be clearly indicated on the boring log following the soil description. Stratigraphic units and their contacts shall be noted wherever possible.

Bedrock Descriptions: If the soil boring penetrates bedrock, the boring log form shall indicate the rock type, color, weathering, fracturing, competency, mineralogy (including secondary mineral assemblages), structure, age (if known), and any other information available. If bedrock drilling is planned, the FTL, with the concurrence of the Project Manager, shall make arrangements to provide the field team with appropriate definitions and other pertinent information that shall be collected.

5.0 REFERENCES

ASTM, 2000, Standard D 2488 - 00 Standard Practice for Description and Identification of Soils (Visual-Manual Procedure).

Macbeth, 1992, Munsell Soil Color Charts.

STANDARD OPERATING PROCEDURES 3

TRENCHING AND TEST PITTING

STANDARD OPERATING PROCEDURES

SOP-3

TRENCHING AND TEST PITTING

TABLE OF CONTENTS

Section **Page**

1.0 INTRODUCTION

This standard operating procedure establishes guidelines for conducting test pit and trench excavations at hazardous waste sites.

Shallow test pits accomplish the following:

- Permit the in-situ condition of the ground to be examined in detail both laterally and vertically
- Provide access for taking samples and for performing in-situ tests
- Provide a means of determining the orientation of discontinuities in the ground

In suitable ground, shallow excavations may provide an efficient and economic method to evaluate the shallow subsurface environment of a site.

2.0 DEFINITIONS

Trench or Test Pit	Linear excavation, of varying width, usually used as an exploratory method to locate landfill boundaries or buried structures, or to characterize the soil/fill sequence at a site.
Ground Crew	Composed of excavating support crew and sampling crew.

3.0 RESPONSIBILITIES

The **Project Manager** selects site-specific soil sampling methods with input from the Site Geologist/Field Team Leader and oversees preparation of heavy equipment/explosive ordnance detection subcontract.

The **Site Geologist/Field Team Leader** selects excavation options, implements the trenching/test pit program, assists in the preparation of technical provisions, and prepares subcontracts.

The **Sampling Crew** performs sampling procedures.

4.0 TRENCH AND TEST PIT CONSTRUCTION

4.1 GENERAL

Trench and test pit excavation is carried out either manually or by using standard equipment such as backhoes, trenching machines, track dozers, track loaders, excavators, and scrapers. Operators of excavating equipment must be skilled and experienced in its safe use for digging test pits and trenches. A typical excavator with an extending backhoe arm can excavate to a depth of approximately 15 feet. If investigations are required to penetrate beyond 15 feet, soil borings may be a more feasible method.

A tailgate safety meeting is conducted by a designated on-site safety officer before commencing excavation.

Prior to all excavations, the Field Team Leader must confirm that underground utilities (electric, gas, telephone, water, etc.) within the proposed areas of excavation have been cleared or marked off. Certain underground services may not be picked up by detectors. Careful excavation, use of probing rods, and the ground crew watching for early signs can help prevent damaging or puncturing underground services.

Prior to commencing excavation, standard signals shall be developed and reviewed for rapid and efficient communication between the backhoe operator and the ground crew. Before approaching areas with operating equipment, the sampling and support crew must verify that the operator has noted their presence.

Upon locating the area for excavation, the backhoe operator determines wind direction and positions the machine upwind of the area of excavation. The backhoe operator outlines the area of investigation by extending the bucket arm to its maximum length and traces a 180-degree outline around the area to be excavated. The support crew cordons off the exclusion zone with a wooden lath and brightly colored "caution" tape, or other appropriate temporary fencing.

Once the excavation equipment has been positioned and stabilized, excavation can commence. If the area of investigation is beneath vegetative cover or surface debris, the backhoe operator removes the surface material to allow a clear and safe working area. Excavated soil is stockpiled away from the immediate edge to one side of the trench to prevent excavated soil from re-entering the trench or test pit and to reduce pressure on the sidewalls. When possible, the soil is deposited downwind of the ground crew and the machine operator. Shifting winds may cause the machine and its operator and the ground crew to periodically move in order to remain upwind. Under some conditions where remaining upwind is not possible, it may be necessary to curtail further activities. The support crew should regularly check the machine operator who, if in a partially enclosed cabin, may be susceptible to fumes/gases.

4.1.1 Safety Procedures

Entry of personnel into pits or trenches is strictly prohibited unless specifically approved and strict adherence to state and federal Occupational Safety and Health Administration guidelines is observed.

Unless full lateral support of the side walls is provided, personnel should never trench deeper than 4 feet (chest height) when personnel will be working in the trench. Any personnel entering the trench may be exposed to toxic or explosive gases and an oxygen-deficient environment. Air monitoring is required before and during entry and appropriate respiratory gear, protective clothing, and egress/rescue equipment is mandatory. Caution should be exercised at all times.

At least two people must be present at the immediate site. Ladder access/egress out of the pit must be installed before entry. Two ladders for worker access/egress must be provided for every 25 feet of lateral distance of a trench and, at a minimum, ladders shall be positioned at opposite ends of trenches less than 25 feet in length.

Care should be taken to ensure that personnel do not stand too close to the edge of the trench especially during sampling or depth measurements; the combination of depositing soil adjacent to the pit and the risk of caving or toppling of the side walls in unstable soils can lead to unsafe conditions.

4.1.2 Stability

Depending on the desired depth of excavation, the trench may require shoring to prevent the sides from collapsing. Lateral support may be provided by a support frame system, or by benching or sloping the sides of the excavation or trench to an appropriate angle. Any timbering or support systems must be installed by qualified personnel.

Groundwater may be pumped out of the pit to stabilize the sidewalls and to keep the excavation dry, allowing a greater depth to be reached especially in granular materials that are below the water table.

Near-vertical slopes can stand for seconds or months, depending on the types of material involved and various other factors affecting the stability. Although personnel should not be entering the excavation, it is prudent to know the possible behavior of the various soil types and conditions that may be encountered. Excavations into fill are generally much more unstable than those in natural soil.

Excavations in very soft, normally consolidated clay may stand vertically without support for short periods. Long-term stability is dependent on a combination of factors: the type of soils, pore pressures, and other forces acting within the soil, and adverse weather effects. Fissured clays can fail along well-defined shear planes; therefore, their long-term stability is not dependent on their shear strength and is difficult to predict.

Dry sands and gravels can stand at slopes equal to their natural angle of repose no matter what the depth of the excavation (angles can range from approximately 28 to 46 degrees depending on the angularity of grains and relative density).

Damp sands and gravels possess some cohesion and can stand vertically for short periods. Water-bearing sands, however, are very difficult in open excavations. If they are cut steeply, as in trench excavation, seepage of water from the face will result in erosion at the toe followed by collapse of the upper part of the face until a stable angle of approximately 15 to 20 degrees is obtained.

Dry silts may stand unsupported vertically, especially if slightly cemented. Wet silt is the most troublesome material to excavate. Seepage leads to slumping and undermining with subsequent collapse, eventually reaching a very shallow angle of repose.

It should not be taken for granted that excavations in rock will stand with vertical slopes unsupported. Their stability depends on the soundness, angle of bedding planes, and the degree of shattering. Unstable conditions can occur if bedding planes slope steeply towards the excavation, especially if groundwater is present to act as lubrication.

4.2 FIELD RECORDING AND SAMPLING TECHNIQUES

The field record should include a plan giving the location, dimensions, and orientation of the pit, together with dimensioned sections of the sidewalls, description of the strata encountered, and details of any sampling or testing carried out. A photographic record of the test pit, with an appropriate scale, would be ideal.

Any groundwater encountered should be noted with regard to its depth and approximate rate of seepage. If possible, the groundwater level within the test pit should be monitored for 20 minutes, with readings taken at 5-minute intervals.

Working from the ground surface the technician can prepare a visual log of the strata/soil profile and decide the interval of sampling. Samples from excavations can be either disturbed or undisturbed.

Disturbed samples are taken from the excavator bucket or from the spoil. To obtain a representative sample of the material at a certain depth, care must be taken not to include scrapings from the sidewalls.

Undisturbed samples may be block samples, cut from in situ material; tube samplers may be driven into the floor of the pit using a jarring link and drill rods and extracted using the backhoe of the excavator.

Samples of groundwater or leachate may be taken using telescoping poles or a small bailer.

The required size of the samples will vary according to the intended analysis/testing to be carried out.

4.3 BACKFILLING

The test pits or trenches should be backfilled immediately upon completion of the hole. Prior to backfilling, pits and test trenches should be inspected to make sure it is safe to approach the excavation with the backfill and equipment. Poorly compacted backfill will cause settlement at the ground surface and hence the spoil should be recompacted in several thin layers using the excavator bucket and any surplus material placed over the top of the pit.

If a sealing layer has been penetrated during excavation, resulting in a groundwater connection between contaminated and previously uncontaminated zones, the backfill material must represent the original conditions or be impermeable. Backfill material could comprise a soil-bentonite mix or a cement-bentonite grout.

4.4 DECONTAMINATION

The purpose of decontamination and cleaning procedures during sampling tasks is to prevent foreign contamination of the samples and cross contamination between sites. All sampling and excavation equipment must be decontaminated before use.

5.0 REFERENCES

Scientific and Technical Standards for Hazardous Waste Sites, Book 1, Volume 1, Site Characterization, August 1990.

Tomlinson, M.J., 1986. *Foundation Design and Construction*, 5th Edition.

Chapter 4

CLASSIFICATION OF ROCKS AND DESCRIPTION OF PHYSICAL PROPERTIES OF ROCK

Introduction

Uniformity of definitions, descriptors, and identification of rock units is important to maintain continuity in geologic logs, drawings, and reports from a project with multiple drilling sessions, different loggers and mappers. Also important is the recording of all significant observable parameters when logging or mapping. This chapter presents a system for the identification and classification of rocks and includes standard terminology and descriptive criteria for physical properties of engineering significance. The standards presented in this chapter may be expanded or modified to fit project requirements.

Rock Classification

Numerous systems are in use for field and petrographic classification of rocks. Many classifications require detailed petrographic laboratory tests and thin sections, while others require limited petrographic examination and field tests. The Bureau of Reclamation (Reclamation) has adopted a classification system which is modified from R.B. Travis [1]. While not based entirely on field tests or field identification of minerals, many of the classification categories are sufficiently broad that field identification is possible. Even where differences in the mineral constituents cannot be determined precisely in the field, differences usually are not significant enough to affect the engineering properties of the rock if classified somewhat incorrectly by lithologic name. Detailed mineralogical identification and petrographic classification can be performed on hand samples or core samples submitted to a petrographic laboratory.

If samples are submitted to a petrographic laboratory, the petrographic classification generally will coincide with the classification according to Travis. The petrographic igneous rock classifications are somewhat more precise and include specialty rock types based upon mineral composition, texture, and occurrence. For example, a lamprophyric dike composed of green hornblende phenocrysts or clinopyroxene in the groundmass could be classified as spessartite, whereas a lamprophyre containing biotite with or without clinopyroxene could be classified as a kersantite. Sedimentary rock classifications generally include grain size, type of cement or matrix, mineral composition in order of increasing amounts greater than 15 percent, and the rock type, such as medium-grained, calcite-cemented, feldspathic-quartzose sandstone, and coarse- to fine-grained, lithic-feldspathic-quartzose gray-wacke with an argillaceous-ferruginous-calcareous matrix. Metamorphic rock classifications include specific rock types based upon crystal size, diagnostic accessory minerals, mineralogical composition in increasing amounts greater than 15 percent, and structure. Two examples of metamorphic rock descriptions are medium-grained, hornblende-biotite schist, or fine- to medium-grained, garnetiferous, muscovite-chlorite-feldspar-quartz gneiss. The above classification can be abbreviated by the deletion of mineral names from the left to right as desired. The mineral type immediately preceding the rock name is the most diagnostic.

The term "quartzite" is restricted to a metamorphic rock only. The sedimentary sandstone equivalent is termed a "quartz cemented quartzose sandstone."

Samples submitted to a petrographic laboratory should be representative of the in-place rock unit. For example, if a granitic gneiss is sampled but only the granite portion submitted, the rock will be petrographically classified as a granite since the gneissic portion cannot be observed or substantiated by the thin section and hand specimen. Petrographic classifications can be related to the engineering properties of rock units and are important.

Geologic rock unit names should be simple, and general rock names should be based on either field identification, existing literature, or detailed petrographic examination, as well as engineering properties. Overclassification is distracting and unnecessary. For example, use "hornblende schist" or "amphibolite" instead of "sericite-chlorite-calcite-hornblende schist." The term "granite" may be used as the rock name and conveys more to the designer than the petrographically correct term "nepheline-syenite porphyry." Detailed mineralogical descriptions may be provided in reports when describing the various rock units and may be required to correlate between observations, but mineralogical classifications are not desirable as a rock unit name unless the mineral constituents or fabric are significant to engineering properties.

The classification for igneous, sedimentary, metamorphic, and pyroclastic rocks is shown on figures 4-1, 4-2, 4-3, and 4-4, respectively. These figures are condensed and modified slightly from Travis' classifications, but the more detailed original classifications of Travis are acceptable. Figure 4-5 or appropriate American Geological Institute (AGI) data sheets are suggested for use when estimating composition percentages in classification.

Description of Rock

Adequate descriptors, a uniform format, and standard terminology must be used for all geologic investigations to properly describe rock foundation conditions. These

COLOR		LIGHT →							DARK		
QUARTZ		> 10 %	< 10 %	> 10 %	< 10 %	> 10 %		< 10 %		CHIEFLY PYROXENE AND/OR OLIVINE	SPECIAL TYPES
FELDSPAR		POTASSIUM FELDSPAR > 2/3 TOTAL FELDSPAR		POTASSIUM FELDSPAR 1/3-2/3 TOTAL FELDSPAR		PLAGIOCLASE > 2/3 TOTAL FELDSPAR					
						K-SPAR > 10 % TOTAL	SODIC PLAGIOCLASE		CALCIC PLAGIOCLASE		
CHIEF ACCESSORY MINERALS		HORNBLENDE BIOTITE MUSCOVITE		HORNBLENDE BIOTITE PYROXENE		HORNBLENDE, BIOTITE, PYROXENE			PYROXENE OLIVINE	SERPENTINE IRON ORE	
Fine to coarse > 1 mm	EQUIGRANULAR Batholiths, lopoliths, stocks, large laccoliths, thick dikes and sills.	GRANITE	SYENITE	QUARTZ MONZONITE	MONZONITE	GRANODIORITE	QUARTZ DIORITE	DIORITE	GABBRO	PERIDOTITE	PEGMATITIE - Very coarse grained, normally silicic, rock (or small irregular mass). APLITE - Fine-grained rock having sugary texture. LAMPROPHYRE - Dark rock with high percentage FeMg materials as phenocrysts and in ground mass.
PORPHYRITIC *	FINE TO COARSE GRAIN GROUND MASS Laccoliths, dikes, sills, plugs, small stocks, margins, of larger masses	GRANITE PORPHYRY	SYENITE PORPHYRY	QUARTZ MONZONITE PORPHYRY	MONZONITE PORPHYRY	GRANODIORITE PORPHYRY	QUARTZ DIORITE PORPHYRY	DIORITE PORPHYRY	GABBRO PORPHYRY	PERIDOTITE PORPHYRY	
PORPHYRITIC *	APHANITIC GROUND MASS Dikes, sills, laccoliths, surface flows, margins of larger masses, welded tuffs.	RHYOLITE PORPHYRY	TRACHYTE PORPHYRY	QUARTZ LATITE PORPHYRY	LATITE PORPHYRY	DACITE PORPHYRY		ANDESITE PORPHYRY	BASALT PORPHYRY	RARE	* TRAP - dark-colored aphanitic rock, * FELSITE - light-colored aphanitic rock.
APHANITIC < 0.1 MM	MICROCRYSTALLINE Dikes, sills, surface flows, margins of larger masses, welded tuffs.	RHYOLITE	TRACHYTE	QUARTZ LATITE	LATITE	DACITE		ANDESITE	BASALT		
APHANITIC < 0.1 MM	GLASSY Surface flows, margins of dikes and sills, welded tuffs.	OBSIDIAN - dark colored PITCHSTONE - resinous VITROPHYRE - porphyritic PERLITE - concentric fractures PUMICE - light colored, finely vesicular SCORIA - dark colored, coarsely vesicular			Normally it is not possible to determine the compositon of these rocks. They are customarily designated by the names at the left. Basic glass is rare so rocks named, except scoria, will normally be silicic. If the approximate composition (by close association) can be determined, the name may be prefixed by the name of the appropriate aphanitic rock, for example, "trachyte obsidian" or "latite vitrophyre". In general, scoria is basic; basic obsidian is called "tachylite"; and spherulite tachylite is "variolite".						* These are somewhat vague terms and generally should not be used.

* The names in these rows should be used if there are >50% phenocrysts. If there are < 50% phenocrysts, the adjective "porphyritic" should be used, for example, "porphyritic granite".

Figure 4-1.—Field classification of igneous rocks (modified after R.B. Travis [1955]).

TEXTURE →	GRAIN SIZE <0.0625 mm			GRAIN SIZE 0.0625 - 2 mm						GRAIN SIZE >2 mm	
	CRYSTALLINE, CLASTIC, AMORPHOUS, BIOCLASTIC, ETC.			CLASTIC						CLASTIC	
COMPOSITION OF MAJOR FRACTION →	CLAY MINERALS or Clay-size Materials	Composition as indicated in left column	CHIEFLY CALCITE OR DOLOMITE	CHIEFLY QUARTZ	QUARTZ with 10-25% FELDSPAR	QUARTZ with >10% ROCK FRAGMENTS	QUARTZ with > 25% FELDSPAR	QUARTZ FELDSPAR ROCK FRAGMENTS	PYROCLASTICS	CHIEFLY ONE CONSTITUENT Homogeneous breccias and conglomerates	SEVERAL CONSTITUENTS Mixed breccias and conglomerates
COMPOSITION OF MINOR FRACTION: <10 % MINOR FRACTION			LIMESTONE, DOLOMITE, ETC.	QUARTZOSE SANDSTONE	FELDSPATHIC SANDSTONE	LITHIC SANDSTONE	ARKOSE	GRAYWACKE	Refer to Figure II-4-4 for classification of Pyroclastics	Name consists of chief constituent and size, as QUARTZ COBBLE CONGLOMERATE, LIMESTONE PEBBLE BRECCIA, ETC.	Name consists of "mixed" and size, as MIXED BOULDER BRECCIA. Name may include composition as ANDESITE-CHERT-ARKOSE CONGLOMERATE
CLAY MINERALS or Clay-size materials	CLAYSTONE, SILTSTONE - nonfissile SHALE - fissile ARGILLITE - highly indurated BENTONITE - sodium montmorillinite		ARGILLACEOUS LIMESTONE, MARL, ETC.	ARGILLACEOUS QUARTZOSE SANDSTONE	ARGILLACEOUS FELDSPATHIC SANDSTONE	ARGILLACEOUS LITHIC SANDSTONE	ARGILLACEOUS ARKOSE	ARGILLACEOUS GRAYWACKE		ARGILLACEOUS (SIZE CONGLOMERATE	ARGILLACEOUS MIXED CONGLOMERATE, GLACIAL TILL, FANGLOMERATE
SILICA OPAL CHALCEDONY QUARTZ CHERT	SILICEOUS SHALE, SILCEOUS CLAYSTONE, ETC.	DIATOMITE, RADIOLARITE, SILICEOUS OOLITE, OOLITE CHERT,	SILICEOUS LIMESTONE, CHERTY LIMESTONE, ETC.	SILICEOUS QUARTZOSE SANDSTONE	SILICEOUS FELDSPATHIC SANDSTONE	SILICEOUS LITHIC SANDSTONE	SILICEOUS ARKOSE	SILICEOUS GRAYWACKE		SILICEOUS (SIZE) CONGLOMERATE	SILICEOUS MIXED (SIZE) CONGLOMERATE
CALCITE OR DOLOMITE	CALCAREOUS SHALE, ETC.	LIMESTONE DOLOMITE CLASTIC LIMESTONE CALICHE - lime-rich deposit formed near surface OOLITE LIMESTONE FOSSILIFEROUS LIMESTONE CHALK		CALCAREOUS QUARTZOSE SANDSTONE	CALCAREOUS FELDSPATHIC SANDSTONE	CALCAREOUS LITHIC SANDSTONE	CALCAREOUS ARKOSE	CALCAREOUS GRAYWACKE		CALCAREOUS (SIZE) CONGLOMERATE	CALCAREOUS MIXED (SIZE) CONGLOMERATE

Rocks including significant quantities of iron, carbon, or miscellaneous salts follow the above format. For example: ferruginous quartzose sandstone, coal, carbonaceous shale, gypsum, phosphatic limestone.

Figure 4-2.—Field classification of sedimentary rocks (modified after R.B. Travis [1955]).

<table>
<tr><th rowspan="4">COLOR</th><th rowspan="4">CHIEF MINERALS</th><th rowspan="4">ACCESSORY MINERALS</th><th colspan="2">NONDIRECTIONAL STRUCTURE (MASSIVE OR GRANULOSE)</th><th colspan="6">DIRECTIONAL STRUCTURE (LINEATED OR FOLIATED)</th></tr>
<tr><th colspan="2">CONTACT METAMORPHISM</th><th>MECHANICAL METAMORPHISM</th><th colspan="4">REGIONAL METAMORPHISM
HIGHLY FOLIATED ← → LESS FOLIATED</th><th>PLUTONIC METAMORPHISM</th></tr>
<tr><th rowspan="2">FINE</th><th rowspan="2">FINE TO COARSE</th><th rowspan="2">CATACLASTIC</th><th>SLATY</th><th>PHYLLITIC</th><th>SCHISTOSE</th><th>GNEISSOSE</th><th rowspan="2">MIGMATITIC</th></tr>
<tr><th>APHANITIC</th><th>FINE</th><th colspan="2">FINE TO COARSE</th></tr>
<tr><td rowspan="4">LIGHTER ↔ DARKER</td><td>FELDSPAR</td><td rowspan="11">ACTINOLITE
ALBITE
ANDALUSITE
ANTHOPHYLLITE
BIOTITE
CHIASTOLITE
CHLORITE
CHLORITIOD
CORDIERITE
DIOPSIDE
ENSTATITE
EPIDOTE
GARNET
GLAUCOPHANE
GRAPHITE
KYANITE
MUSCOVITE
OLIVINE
PYROPHYLLITE
PHLOGOPITE
SCAPOLITE
SERICITE
SERPENTINE
SILLIMANITE
STAUROLITE
TOURMALINE
TREMOLITE
WOLLASTONITE</td><td rowspan="11">HORNFELS</td><td rowspan="2">METAQUARTZITE</td><td rowspan="11">These rocks are formed by crushing with only minor recrystallization

CATACLASITE
Nondirectional

MYLONITE
Foliated, aphanitic

PHYLLONITE
Foliated, fine grain, resembles a phyllite.

FLASER GRANITE, FLASER DIORITE, FLASER CONGLOMERATE ETC. -
Flaser structure, lenses and layers of original or relatively unaltered granular minerals surrounded by matrix of highly sheared and crushed material.

AUGEN GNEISS -
Augen structure</td><td rowspan="11">SLATE</td><td rowspan="11">PHYLLITE</td><td rowspan="10">SCHIST
(AMPHIBOLITE)

GNEISSIC SCHIST</td><td rowspan="11">GNEISS

AUGEN GNEISS

SCHISTOSE GNEISS</td><td rowspan="11">These rocks have a gneissose, streaked, or irregular structure produced by intimate mixing of metamorphic and magmatic materials. When they can be recognized as "mixed rock", they are called migmatite gneiss. They may originate by injection (injection migmatite, injection gneiss, or lit-par-lit gneiss), or by differential fusion. Many so-called migmatites probably originate by partial granitization or by metamorphic differentiation. But at great depth these processes apparently do not differ substantially from the igneous processes forming migmatite, so the products are usually indistinguishable.
Migmatities are named by prefixing the rock name of the granitic material to the appropriate root as "granite mignatite", "monzonite injection mignatite", etc.</td></tr>
<tr><td>QUARTZ</td></tr>
<tr><td>MICA</td><td rowspan="5">AMPHIBOLITE</td></tr>
<tr><td>HORNBLENDE</td></tr>
<tr><td rowspan="3"></td><td>CHLORITE</td></tr>
<tr><td>ACTINOLITE</td></tr>
<tr><td>TREMOLITE</td></tr>
<tr><td rowspan="4">LIGHTER ↔ DARKER</td><td>TALC</td><td>SOAPSTONE</td></tr>
<tr><td>CALCITE AND/OR DOLOMITE</td><td>MARBLE</td></tr>
<tr><td>CALC-SILICATES</td><td>SKARN</td></tr>
<tr><td>SERPENTINE</td><td>SERPENTINITE</td><td>SERPENTINITE</td></tr>
</table>

Naming a metamorphic rock consists chiefly of prefixing the structural term with mineral names or an appropriate rock name. The rock name indicates either the original rock, if recognizable, or the new mineral composition. The prefix "meta", as "Metagabbro", "metasandstone", "metatuff", etc., is applied to rocks that have undergone considerable recrystallization but have largely retained their original fabric. Most of the minerals listed as accessories are genetically important and if present should be included in the rock name regardless of their quantity.

Figure 4-3.—Field classification of metamorphic rocks (modified after R.B. Travis [1955]).

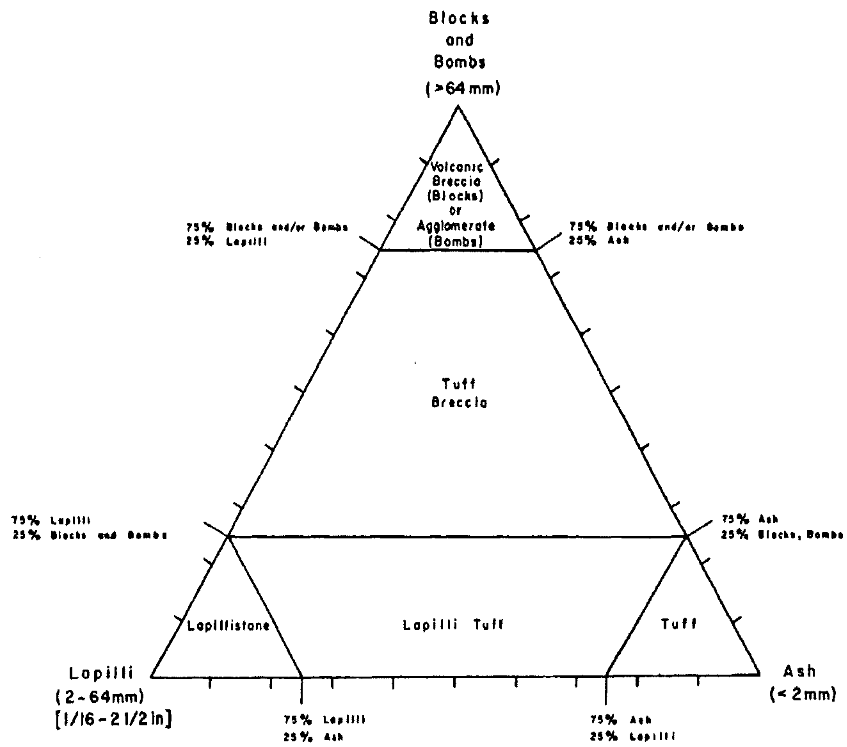

Figure 4-4.—Field classification of pyroclastic rocks. Blocks are angular to subangular clasts > 64 millimeters (mm); bombs are rounded to subrounded clasts > 64 mm. Determine percent of each size present (ash, lapilli, blocks, and bombs) and list in decreasing order after rock name. Preceed rock name with the term "welded" for pyroclastic rocks which retained enough heat to fuse after deposition. Rock names for such deposits are usually selected from the lower right portion of the classification diagram above. (Modified from Fisher, 1966 [2] and Williams and McBirney, 1979 [3]).

paragraphs provide descriptors for those physical characteristics of rock that are used in logs of exploration, in narratives of reports, and on preconstruction geologic maps and cross sections, as well as construction or "as-built" drawings. The alphanumeric descriptors provided may be used in data-field entries of computer generated

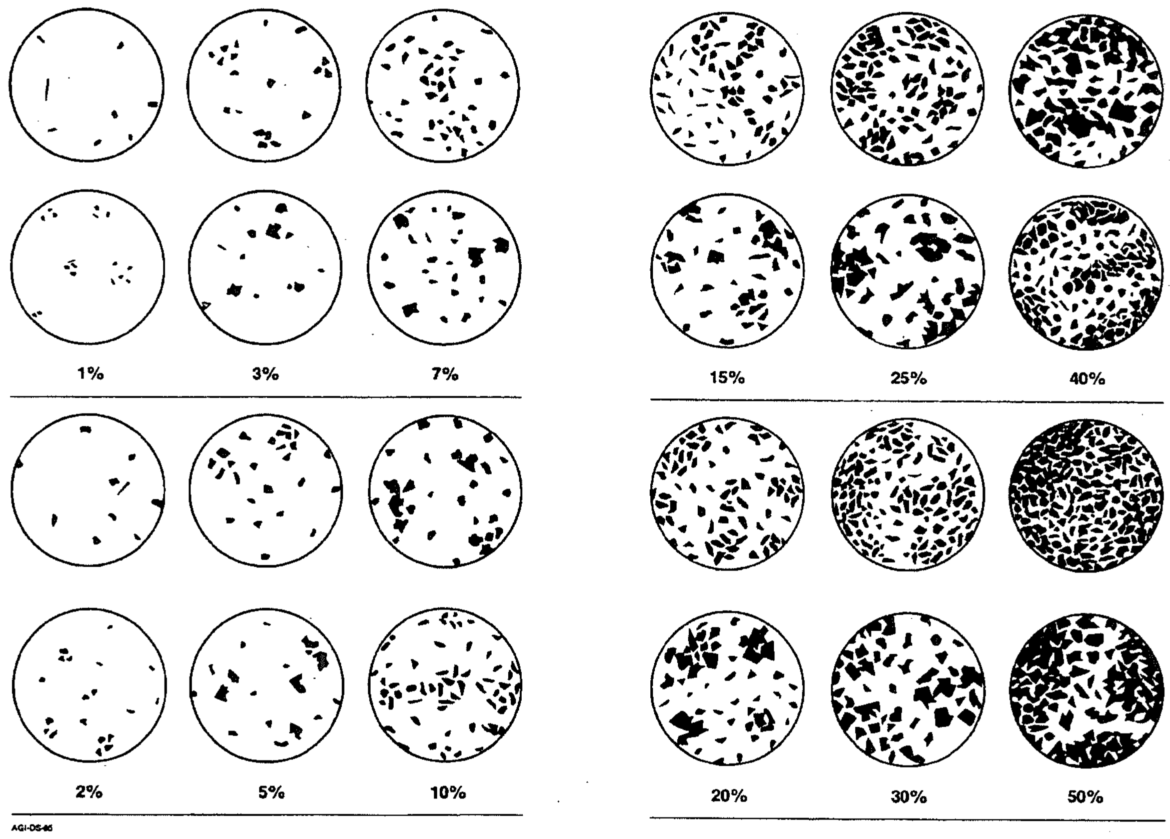

Figure 4-5.—Charts for estimating percentage of composition of rocks and sediments.[4]

logs. Chapter 5 establishes descriptors for the physical characteristics of discontinuities in rock required for engineering geologic studies.

All descriptors should be defined and included in a legend when submitting data for design and/or records of construction. An example of a legend and explanation is figure 4-6, Reclamation standard drawing 40-D-6493, may be used for geologic reports and specifications where the standard descriptors and terminology established for rock are used during data collection.

Format for Descriptions of Rock

Engineering geology rock descriptions should include generalized lithologic and physical characteristics using qualitative and quantitative descriptors. A general format for describing rock in exploration logs and legends on general note drawings is:

- Rock unit (member or formation) name
- Lithology with lithologic descriptors
  - composition (mineralogy)
  - grain/particle size
  - texture
  - color
- Bedding/foliation/flow texture
- Weathering
- Hardness/strength
- Contacts
- Discontinuities (includes fracture indexes)
- Permeability data (as available from testing)
- Moisture conditions

Example descriptions are presented in a later section.

Rock Unit Names and Identification

Rock unit names not only are required for identification purposes but may also provide indicators of depositional environment and geologic history, geotechnical characteristics, and correlations with other areas. A simple descriptive name and map symbol should be assigned to provide other users with possible engineering characteristics of the rock type. The rock unit names may be stratigraphic, lithologic, genetic, or a combination of these, such as Navajo Sandstone (Jn), Tertiary shale (Tsh), Jurassic chlorite schist (Jcs), Precambrian granite (Pcgr), or metasediments (ms). Bedrock units of similar physical properties should be delineated and identified as to their engineering significance as early as possible during each geologic study. Planning study maps and other large-scale drawings may require geologic formations or groups of engineering geologic units with descriptions of their engineering significance in accompanying discussions.

Units should be differentiated by engineering properties and not necessarily formal stratigraphic units where differences are significant. Although stratigraphic names are not required, units should be correlated to stratigraphic names in the data report or by an illustration, such as a stratigraphic column. Stratigraphic names and ages (formation, member) may be used as the rock unit name.

For engineering studies, each particular stratigraphic unit may require further subdivisions to identify engineering parameters. Examples of important engineering properties are:

- Susceptibility to weathering or presence of alteration

ROCKS

WEATHERING

FRESH (W1): Body of rock is not oxidized or discolored; fracture surfaces are not oxidized or discolored*; no separation of grain boundaries; no change of texture and no solutioning. Hammer rings when crystalline rocks are struck.

SLIGHTLY WEATHERED TO FRESH (W2):**

SLIGHTLY WEATHERED (W3): Discoloration or oxidation is limited to surface of, or short distance from fractures; some feldspar crystals are dull; fracture surfaces have minor to complete discoloration or oxidation; no visible separation of grain boundaries; texture preserved and minor leaching of soluble minerals may be present. Hammer rings when crystalline rocks are struck, body of rock is not weakened by weathering.

MODERATELY TO SLIGHTLY WEATHERED (W4):**

MODERATELY WEATHERED (W5): Discoloration or oxidation extends from fractures, usually throughout body of rock; ferromagnesian minerals are "rusty," feldspar crystals are "cloudy;" all fracture surfaces are discolored or oxidized; partial opening of grain boundaries visible; texture generally preserved but soluble minerals may be mostly leached. Hammer does not ring when rock is struck, body of rock is slightly weakened.

INTENSELY TO MODERATELY WEATHERED (W6):**

INTENSELY WEATHERED (W7): Body of rock is discolored or oxidized throughout; all feldspars and ferromagnesian minerals are altered to clay to some extent. All fracture surfaces are discolored or oxidized, surfaces friable; partial separation of grain boundaries, rock is friable; in situ disaggregation of granitics common in semi-arid regions; texture altered and leaching of soluble minerals may be complete. Rock has dull sound when struck with hammer; rock is weakened, usually can be broken with moderate to heavy manual pressure or by light hammer blow without reference to planes of weakness.

VERY INTENSELY WEATHERED (W8):**

DECOMPOSED (W9): Body of rock is discolored or oxidized throughout, but resistant minerals such as quartz may be unaltered; all feldspars and ferromagnesian minerals are completely altered to clay; complete separation of grain boundaries (disaggregated), partial or complete remnant rock structure may be preserved, but resembles a soil.

NOTE: Weathering categories are established primarily for crystalline rocks and those with ferromagnesian minerals, weathering in various sedimentary rocks will not always fit the categories established - weathering categories may be modified for particular site conditions or alteration such as hydrothermal alteration. Where modified criteria are established, they are identified and described.

* Characteristics of fracture surfaces do not include directional weathering along shears or faults and their associated fracture zones; for example a shear that carries weathering to great depths in a fresh rock mass would not require the whole rock mass to be classified as weathered.

** Combination descriptors are used where equal distribution of both weathering characteristics are present over significant intervals or where characteristics noted are "in between" the diagnostic characteristics.

DURABILITY INDEX

DURABILITY DESCRIPTOR	DESCRIPTIVE CRITERIA
DI0	Rock specimen or exposure remains intact with no deleterious cracking after exposure longer than 1 year.
DI1	Rock specimen or exposure develops hairline cracking on surfaces within 1 month, but no disaggregation within 1 year of exposure.
DI2	Rock specimen or exposure develops hairline cracking on surfaces within 1 week, and/or disaggregation within 1 month of exposure.
DI3	Specimen or exposure may develop hairline cracks in 1 day and displays pronounced separation of bedding and/or disaggregation within 1 week of exposure.
DI4	Specimen or exposure displays pronounced cracking and disaggregation within 1 day (24 hours) of exposure. Generally ravels and degrades to small fragments.

COLOR

The Munsell color system (Geologic Society of America Rock Color Chart) was used. This system defines wet color by its hue, value, and chroma. Color symbols (i.e., 5 YR 5/6 may be included).

SEDIMENTARY AND PYROCLASTIC ROCK PARTICLE SIZES

Size in mm	Sedimentary (Rounded, subrounded, subangular): Particle or fragment	Sedimentary: Lithified product	Pyroclastic: Fragment	Pyroclastic: Lithified product
	Boulder	Boulder conglomerate	Block* or Bomb**	Volcanic breccia* or Volcanic agglomerate**
255	Cobble	Cobble conglomerate		
64	Pebble	Pebble conglomerate	Lapilli	Lapillistone and Lapilli tuff
4	Granule	Granule conglomerate		
2	Very coarse sand	Sandstone	Coarse ash	Coarse tuff
1	Coarse sand			
0.5	Medium sand	(Very coarse, coarse, medium, fine, or very fine)		
0.25	Fine sand			
0.125	Very fine sand			
0.0625	Silt	Siltstone/Shale	Fine ash	Fine tuff
0.00391	Clay	Claystone/Shale		

* Broken from previous igneous rock, block shaped (angular to subangular).
** Solidified from plastic material while in flight, rounded clasts.

IGNEOUS AND METAMORPHIC ROCK TEXTURE

TEXTURE DESCRIPTOR	AVERAGE GRAIN DIAMETER
VERY COARSE GRAINED OR PEGMATITIC	>10 mm [>3/8 in]
COARSE GRAINED	5-10 mm [3/16 - 3/8 in]
MEDIUM GRAINED	1-5 mm [1/32 - 3/16 in]
FINE GRAINED	0.1-1 mm [0.004 - 1/32 in]
APHANITIC (Cannot be seen with the unaided eye)	<0.1 mm [<0.004 in]

ADDITIONAL TEXTURAL ADJECTIVES

PIT (pitted) - Pinhole to 0.03 ft (3/8 in) (<1 to 10 mm) openings.

VUG (vuggy) - Small openings (usually lined with crystals) ranging in diameter from 0.03 ft (3/8 in) to 0.33 ft (4 in) (10 to 100 mm).

CAVITY - An opening larger than 0.33 ft (4 in) (100 mm), size descriptions are required, and adjectives such as small, large, etc., may be used.

HONEYCOMBED - If numerous enough that only thin walls separate individual pits or vugs, this term further describes the preceding nomenclature to indicate cell-like form.

VESICLE (vesicular) - Small openings in volcanic rocks of variable shape and size formed by entrapped gas bubbles during solidification.

BEDDING FOLIATION OR FLOW TEXTURE

DESCRIPTORS	THICKNESS/SPACING
MASSIVE	Greater than 10 ft (>3 m)
VERY THICKLY (bedded, foliated, or banded)	3 to 10 ft (1 to 3 m)
THICKLY	1 to 3 ft (300 mm to 1 m)
MODERATELY	0.3 to 1 ft (100 to 300 mm)
THINLY	0.1 to 0.3 ft (30 to 100 mm)
VERY THINLY	0.03 (3/8 in) to 0.1 ft (10 to 30 mm)
LAMINATED (Intensely foliated or banded)	Less than 0.03 ft (3/8 in) (<10 mm)

BEDROCK HARDNESS / STRENGTH

EXTREMELY HARD (H1): Core, fragment or exposure cannot be scratched with knife or sharp pick; can only be chipped with repeated heavy hammer blows.

VERY HARD (H2): Cannot be scratched with knife or sharp pick. Core or fragment breaks with repeated heavy hammer blows.

HARD (H3): Can be scratched with knife or sharp pick with difficulty (heavy pressure). Heavy hammer blow required to break specimen.

MODERATELY HARD (H4): Can be scratched with knife or sharp pick with light or moderate pressure. Core or fragment breaks with moderate hammer blow.

MODERATELY SOFT (H5): Can be grooved 1/16 inch (2 mm) deep by knife or sharp pick with (moderate or heavy) pressure. Core or fragment breaks with light hammer blow or heavy manual pressure.

SOFT (H6): Can be grooved or gouged easily by knife or sharp pick with light pressure, can be scratched with fingernail. Breaks with light to moderate manual pressure.

VERY SOFT (H7): Can be readily indented, grooved or gouged with fingernail, or carved with a knife. Breaks with light manual pressure.

Note: Bedrock units softer than H7, Very Soft, are described using USCS (soils) consistency descriptors.

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

GEOLOGY FOR DESIGNS & SPECIFICATIONS
STANDARD DESCRIPTORS AND DESCRIPTIVE CRITERIA FOR ROCK

GEOLOGY NOMENCLATURE COMM. TECHNICAL APPROVAL [illegible]
DRAWN [illegible] SUBMITTED [illegible]
CHECKED [illegible] APPROVED [illegible]
CHIEF, DIVISION OF GEOLOGY

DENVER, COLORADO OCTOBER 1, 19[illegible] 40-D-6493

Figure 4-6.—Descriptor legend and explanation example.

- Dominant discontinuity characteristics
- Hardness and/or strength
- Deformability
- Deletereous minerals or beds (such as swelling susceptibility, sulfates, or clays)

For example, a Tertiary shale unit, Tsh, may be differentiated as Tsh_1 or Tsh_2 if unit 2 contains bentonite interbeds and unit 1 does not, and Tsh_c could be used as a unit name for the bentonite beds. A chlorite schist unit, Cs, may be differentiated as Cs_A or Cs_B where unit A contains higher percentages of chlorite or talc and is significantly softer (different deformation properties) than unit B. A metasediment unit, ms, may be further differentiated on more detailed maps and logs as ms_{sh} (shale) or ms_{ls} (limestone). All differentiated units should be assigned distinctive map symbols and should be described on the General Geologic Legend, Explanation, and Notes drawings.

Descriptors and Descriptive Criteria for Physical Characteristics of Rock

Lithologic Descriptors (Composition, Grain Size, and Texture).—Provide a brief lithologic description of the rock unit. This includes a general description of mineralogy, induration, cementation, crystal and grain sizes and shapes, textural adjectives, and color. Lithologic descriptors are especially important for the description of engineering geology subunits when rock unit names are not specific. Examples of rock unit names that are not specific are metasediments, Tertiary intrusives, or Quaternary volcanics.

1. Composition.—Use standard adjectives such as sandy, silty, calcareous, etc. Detailed mineral comp osition generally is not necessary or desirable unless useful in correlating units or indicating pertinent engineering physical properties. Note unique features such as fossils, large crystals, inclusions, concretions, and nodules which may be used as markers for correlations and interpretations.

2. Crystal or particle sizes and shapes.— Describe the typical crystal or grain shapes and provide a description of sizes present in the rock unit based on the following standards:

- Igneous and metamorphic rocks.—Table 4-1 is recommended for descriptions of crystal sizes in igneous and metamorphic rocks. Crystal sizes given in millimeters (mm) are preferred rather than fractional inch (in) equivalents.

Table 4-1.—Igneous and metamorphic rock grain size descriptors

Descriptor	Average crystal diameter
Very coarse-grained or pegmatitic	> 10 mm (3/8 in)
Coarse-grained	5-10 mm (3/16 - 3/8 in)
Medium-grained	1-5 mm (1/32 - 3/16 in)
Fine-grained	0.1-1 mm (0.04 - 1/32 in)
Aphanitic (cannot be seen with the unaided eye	<0.1 mm (<0.04 in)

- Sedimentary and pyroclastic rocks.—Terminology for particle sizes and their lithified products which form sedimentary and pyroclastic rocks is provided in table 4-2. The size

Table 4-2.—Sedimentary and pyroclastic rock particle-size descriptors (AGI Glossary)

USGS (soils only) Particle size	Size in mm (inches)	Sedimentary (epiclastic) Rounded, subrounded, subangular		Volcanic (pyroclastic)	
		Particle or fragment	Lithified product	Frag-ment	Lithified product*
Boulder		Boulder	Boulder conglomerate	Block+	Volcanic breccia+
	300 (12)				
	256 (10)				
Cobble		Cobble	Cobble conglomerate	Bomb	Agglo-merate
	75 (3)				
	64 (2.5)				
Coarse gravel	32 (1.3)	Pebble	Pebble conglomerate	Lapilli	Lapilli tuff
	20 (0.8)				
Fine gravel	4.75 (0.19)				
	4 (0.16)				
Coarse sand		Granule	Granule conglomerate	Coarse ash	Coarse tuff
	2 (0.08)				
Medium sand		Very coarse sand	Sandstone (Very coarse, coarse, medium fine, or very fine)		
	1 (0.04)	Coarse sand			
	0.5 (0.02)				
	0.42	Medium sand			
	0.25	Fine sand			
Fine sand	0.125	Very fine sand			
	0.074				
Fines Non-plastic Silt	0.0625	Silt	Siltstone Shale	Fine ash	Fine tuff
	0.00391				
Plastic Clay		Clay	Claystone Shale		

+ Broken from previous igneous rock block shaped (angular to subangular). Solidified from plastic material while in flight, rounded clasts.

* Refer to figure 4-4.

limits do not correspond to the Unified Soil Classification System for soil particle size but are used for the field description and petrographic classification of rocks. These limits are the accepted sizes in geologic literature and are used by petrographic laboratories.

*3. **Textural adjectives.***—Texture describes the arrangements of minerals, grains, or voids. These microstructural features can affect the engineering properties of the rock mass. Use simple, standard, textural adjectives or phrases such as porphyritic, vesicular, scoriaceous, pegmatitic, granular, well developed grains, dense, fissile, slaty, or amorphous. Use of terms such as holohyaline, hypidiomorphic granular, and crystaloblastic is inappropriate.

Textural terms which identify solutioning, leaching, or voids in bedrock are useful for describing primary texture, weathering, alteration, permeability, and density.

The terminology which follows defines sizes of voids, or holes in bedrock. However, when describing pits, vugs, cavities, or vesicles, a complete description which includes the typical diameter, or the "mostly" range, and the maximum size observed is required. For example:

". . . randomly oriented, elliptically shaped vugs range mostly from 0.03 to 0.06 foot (ft) in diameter, maximum size 0.2 foot; decreases in size away from quartz-calcite vein; about 15 percent contain calcite crystals. . ."

or

". . . cavity, 3.3 ft wide by 16.4 ft long by 2.3 ft high, striking N 45°W, dipping 85°SW was. . .."

- **Pit (pitted).**—Pinhole to 0.03 ft [d in] (<1 to 10 mm) openings.

- **Vug (vuggy).**—Small opening (usually lined with crystals) ranging in diameter from 0.03 ft [d in] to 0.33 ft [4 in] (10 to 100 mm).

- **Cavity.**—An opening larger than 0.33 ft [4 in] (100 mm), size descriptions are required, and adjectives such as small, or large, may be used, if defined.

- **Honeycombed.**—Individual pits or vugs are so numerous that they are separated only by thin walls; this term is used to describe a cell-like form.

- **Vesicle (vesicular).**—Small openings in volcanic rocks of variable shape formed by entrapped gas bubbles during solidification.

4. Color.—As a minimum, provide the color of wet altered and unaltered or fresh rock. Reporting color for both wet and dry material is recommended since the colors may differ significantly and cause confusion. The Munsell Color System, as used in the Geologic Society of America Rock Color Chart [5], is used to provide standard color names and assist in correlation. The chart also provides uniform and identifiable colors to others. Color designators are optional unless necessary for clarity, e.g., light brown (5YR 5/6). Terms such as banded, streaked, mottled, speckled, and stained may be used to further describe color. Also describe colors of bands, etc.

Bedding, Foliation, and Flow Texture.—These features give the rock anisotropic properties or represent potential failure surfaces. Continuity and thickness of these features influence rock mass properties and cannot always be tested in the laboratory. Descriptors in table 4-3 are used to identify these thicknesses.

Table 4-3.—Bedding, foliation, or flow texture descriptors

Descriptors	Thickness/spacing
Massive	Greater than 10 ft (3 meters [m])
Very thickly, bedded, foliated, or banded	3 to 10 ft (1 to 3 m)
Thickly	1 to 3 ft (300 mm to 1 m)
Moderately	0.3 to 1 ft (100 to 300 mm)
Thinly	0.1 to 0.3 ft (30 to 100 mm)
Very thinly	0.03 [3/8 in] to 0.1 ft (10 to 30 mm)
Laminated (intensely foliated or banded)	Less than 0.03 ft [3/8 in] (<10 mm)

Weathering and Alteration.—

1. ***Weathering.***—Weathering, the process of chemical or mechanical degradation of rock, can significantly affect the engineering properties of the rock and rock mass. For engineering geology descriptions, the term "weathering" includes both chemical disintegration (decomposition) and mechanical disaggregation as agents of alteration.

Weathering effects generally decrease with depth, although zones of differential weathering can occur and may modify a simple layered sequence of weathering.

Examples are: (1) differential weathering within a single rock unit, apparently due to relatively higher permeability along fractures; (2) differential weathering due to compositional or textural differences; (3) differential weathering of contact zones associated with thermal effects such as interflow zones within volcanics; (4) directional weathering along permeable joints, faults, shears, or contacts which act as conduits along which weathering agents penetrate more deeply into the rock mass; and (5) topographic effects.

Weathering does not correlate directly with specific geotechnical properties used for many rock mass classifications. However, weathering is important because it may be the primary criterion for determining depth of excavation, cut slope design, method and ease of excavation, and use of excavated materials. Porosity, absorption, compressibility, shear and compressive strengths, density, and resistance to erosion are the major engineering parameters influenced by weathering. Weathering generally is indicated by changes in the color and texture of the body of the rock, color, and condition of fracture fillings and surfaces, grain boundary conditions, and physical properties such as hardness.

Weathering is reported using descriptors presented in table 4-4, which divides weathering into categories that reflect definable physical changes due to chemical and mechanical processes. This table summarizes general descriptions which are intended to cover ranges in bedrock conditions. Weathering tables are generally applicable to all rock types; however, they are easier to apply to crystalline rocks and rocks that contain ferromagnesian minerals. Weathering in many sedimentary rocks will not always conform to the criteria established in table 4-4, and weathering categories may have to be modified for particular site conditions. However, the basic horizontal categories and descriptors presented can be used. Site-specific conditions, such as fracture openness, filling, and degree and depth of penetration of oxidation from fracture surfaces, should be identified and described.

2. ***Alteration.***—Chemical alteration effects are distinct from chemical and mechanical degradation (weathering), such as hydrothermal alteration, may not fit into the horizontal suite of weathering categories portrayed in table 4-4. Oxides may or may not be present. Alteration is site-specific, may be either deleterious or beneficial, and may affect some rock units and not others at a particular site. For those situations where the alteration does not relate well to the weathering categories, adjusting the description within the framework of table 4-4 may be necessary. Many of the general characteristics may not change, but the degree of discoloration and oxidation in the body of the rock and on fracture surfaces could be very different. Appropriate descriptors, such as moderately altered or intensely altered, may be assigned for each alteration category. Alteration products, depths of alteration, and minerals should be described.

3. ***Slaking.***—Slaking is another type of disintegration which affects engineering properties of rock. Terminology and descriptive criteria to identify this deleterious property are difficult to standardize because some materials air slake, many water slake, and some only slake after one or more wet-dry cycles. The Durability Index (DI) is a simplified method for describing slaking. Criteria for the index are based

Table 4-4.—Weathering descriptors

Descriptors		Diagnostic features					General characteristics (strength, excavation, etc.)§
		Chemical weathering—Discoloration and/or oxidation		Mechanical weathering - Grain boundary conditions (disaggregation) primarily for granitics and some coarse-grained sediments	Texture and solutioning		
Alpha-numeric descriptor	Descriptive term	Body of rock	Fracture surfaces†		Texture	Solutioning	
W1	Fresh.	No discoloration, not oxidized.	No discoloration or oxidation.	No separation, intact (tight).	No change.	No solutioning.	Hammer rings when crystalline rocks are struck. Almost always rock excavation except for naturally weak or weakly cemented rocks such as siltstones or shales.
W2	Slightly weathered to fresh.*						
W3	Slightly weathered.	Discoloration or oxidation is limited to surface of, or short distance from, fractures; some feldspar crystals are dull.	Minor to complete discoloration or oxidation of most surfaces.	No visible separation, intact (tight).	Preserved.	Minor leaching of some soluble minerals may be noted.	Hammer rings when crystalline rocks are struck. Body of rock not weakened. With few exceptions, such as siltstones or shales, classified as rock excavation.
W4	Moderately to slightly weathered.*						
W5	Moderately weathered.	Discoloration or oxidation extends from fractures, usually throughout; Fe-Mg minerals are "rusty," feldspar crystals are "cloudy."	All fracture surfaces are discolored or oxidized.	Partial separation of boundaries visible.	Generally preserved.	Soluble minerals may be mostly leached.	Hammer does not ring when rock is struck. Body of rock is slightly weakened. Depending on fracturing, usually is rock excavation except in naturally weak rocks such as siltstone or shales.
W6	Intensely to moderately weathered.*						
W7	Intensely weathered.	Discoloration or oxidation throughout; all feldspars and Fe-Mg minerals are altered to clay to some extent; or chemical alteration produces in situ disaggregation, see grain boundary conditions.	All fracture surfaces are discolored or oxidized, surfaces friable.	Partial separation, rock is friable; in semiarid conditions granitics are disaggregated.	Texture altered by chemical disintegration (hydration, argillation).	Leaching of soluble minerals may be complete.	Dull sound when struck with hammer; usually can be broken with moderate to heavy manual pressure or by light hammer blow without reference to planes of weakness such as incipient or hairline fractures, or veinlets. Rock is significantly weakened. Usually common excavation.
W8	Very intensely weathered.						
W9	Decomposed.	Discolored or oxidized throughout, but resistant minerals such as quartz may be unaltered; all feldspars and Fe-Mg minerals are completely altered to clay.		Complete separation of grain boundaries (disaggregated).	Resembles a soil, partial or complete remnant rock structure may be preserved; leaching of soluble minerals usually complete.		Can be granulated by hand. Always common excavation. Resistant minerals such as quartz may be present as "stringers" or "dikes."

Note: This chart and its horizontal categories are more readily applied to rocks with feldspars and mafic minerals. Weathering in various sedimentary rocks, particularly limestones and poorly indurated sediments, will not always fit the categories established. This chart and weathering categories may have to be modified for particular site conditions or alteration such as hydrothermal effects; however, the basic framework and similar descriptors are to be used.

* Combination descriptors are permissible where equal distribution of both weathering characteristics are present over significant intervals or where characteristics present are "in between" the diagnostic feature. However, dual descriptors should not be used where significant, identifiable zones can be delineated. When given as a range, only two adjacent terms may be combined (i.e., decomposed to lightly weathered or moderately weathered to fresh) are not acceptable.

† Does not include directional weathering along shears or faults and their associated features. For example, a shear zone that carried weathering to great depths into a fresh rock mass would not require the rock mass to be classified as weathered.

§ These are generalizations and should not be used as diagnostic features for weathering or excavation classification. These characteristics vary to a large extent based on naturally weak materials or cementation and type of excavation.

on time exposed and effects noted in the field (see table 4-5). These simplified criteria do not specify whether the specimen or exposure is wetted, dried, or subjected to cyclic wetting and drying, and/or freeze-thaw. When reporting slaking or durability, a complete description includes the test exposure conditions. For example, the material could be classified as having "characteristics of DI 3 upon drying." Slaking is not the same as the effects of bedding separation or disaggregation produced by stress relief.

Table 4-5.—Durability index descriptors

Alpha-numeric descriptor	Criteria
DI0	Rock specimen or exposure remains intact with no deleterious cracking after exposure longer than 1 year.
DI1	Rock specimen or exposure develops hairline cracking on surfaces within 1 month, but no disaggregation within 1 year of exposure.
DI2	Rock specimen or exposure develops hairline cracking on surfaces within 1 week and/or disaggregation within 1 month of exposure.
DI3	Specimen or exposure may develop hairline cracks in 1 day and displays pronounced separation of bedding and/or disaggregation within 1 week of exposure.
DI4	Specimen or exposure displays pronounced cracking and disaggregation within 1 day (24 hours) of exposure. Generally ravels and degrades to small fragments.

A field test suitable for evaluating the degree and rate of slaking for materials, primarily clayey materials and altered volcanics, is described below. The slaking test evaluates the disaggregation of an intact specimen in water and reflects the fabric of the material, internal stresses, and character of the interparticle bonds.

To evaluate slaking behavior, immerse two intact specimens (pieces of core or rock fragments consisting of a few cubic inches or centimeters) in water. One piece should be at natural water content (wrapped jar sample) and one piece from an air-dried sample. Test results should be photographed with labels to identify specimens and exposure times.

Results of the evaluation should be reported for each specimen. Describe the behavior of the specimens as follows:

a. Volume changes.—The volume of the material reduced to individual particles should be estimated and compared to the initial volume of material. The degree of disaggregation is described using the following descriptive criteria:

None	No discernable disaggregation
Slight	Less than 5 percent of the volume disaggregated
Moderate	Between 5 and 25 percent of the volume disaggregated
Intense	More than 25 percent but less than the total volume disaggregated
Complete	No intact piece of the material remains

b. Rate of slaking.—The following descriptors are used to identify the time to slake:

Slow slaking	Action continues for several hours
Moderate slaking	Action completed within 1 hour
Rapid slaking	Action completed within 2 minutes
Sudden slaking	Complete reaction, action completed instantaneously

[Generally, slaking applies to rock; disaggregation applies to soils.]

4. ***Character of material.***—The character of the remaining pieces of material after the test is completed is described as follows:

No change	Material remains intact
Plates remain	Remaining material present as platy fragments of generally uniform thickness
Flakes remain	Remaining material present as flaky or wedge-shaped fragments
Blocks remain	Blocky fragments remain
Grains remain	Remaining material chiefly present as sand-size grains
No fragments	Remaining material entirely disaggregated to clay-size particles

Hardness—Strength.—Hardness can be related to intact rock strength as a qualitative indication of density and/or resistance to breaking or crushing. Strength is a necessary engineering parameter for design that frequently is not assessed, but plays a role in engineering design and construction, such as tunnel support requirements, bit wear for drilling or tunnel boring machine (TBM) operations, allowable bearing pressures, excavation methods, and support.

The hardness and strength of intact rock is a function of the individual rock type but may be modified by weathering or alteration. Hardness and strength are described for each geologic unit when they are functions of the rock type and also for zones of alteration or weathering when there are various degrees of hardness and/or strength due to different degrees of weathering or chemical alteration. When evaluating strengths, it is important to note whether the core or rock fragments break around, along, or through grains; or along or across incipient fractures, bedding, or foliation.

Hardness and especially strength are difficult characteristics to assess with field tests. Two field tests can be used; one is a measure of the ability to scratch the surface of a specimen with a knife, and the other is the resistance to fracturing by a hammer blow. Results from both tests should be reported. The diameter and length of core or the fragment size will influence the estimation of strength and should be kept in mind when correlating strengths. A 5- to 8-inch (130- to 200-mm) length of N-size core or rock fragment, if available, should be used for hardness determinations to preclude erroneously reporting point, rather than average hardness, and to evaluate the tendency to break along incipient fractures and textural or structural features when struck with a rock pick. Standards (heavy, moderate, and light hammer blow) should be calibrated with other geologists mapping or logging core for a particular project. Descriptors used for rock hardness/strength are shown on table 4-6.

Table 4-6.—Rock hardness/strength descriptors

Alpha-numeric descriptor	Descriptor	Criteria
H1	Extremely hard	Core, fragment, or exposure cannot be scratched with knife or sharp pick; can only be chipped with repeated heavy hammer blows.
H2	Very hard	Cannot be scratched with knife or sharp pick. Core or fragment breaks with repeated heavy hammer blows.
H3	Hard	Can be scratched with knife or sharp pick with difficulty (heavy pressure). Heavy hammer blow required to break specimen.
H4	Moderately hard	Can be scratched with knife or sharp pick with light or moderate pressure. Core or fragment breaks with moderate hammer blow
H5	Moderately soft	Can be grooved 1/16 inch (2 mm) deep by knife or sharp pick with moderate or heavy pressure. Core or fragment breaks with light hammer blow or heavy manual pressure.
H6	Soft	Can be grooved or gouged easily by knife or sharp pick with light pressure, can be scratched with fingernail. Breaks with light to moderate manual pressure.
H7	Very soft	Can be readily indented, grooved or gouged with fingernail, or carved with a knife. Breaks with light manual pressure.

Any bedrock unit softer than H7, very soft, is to be described using USBR 5000 consistency descriptors.

Note: Although "sharp pick" is included in these definitions, descriptions of ability to be scratched, grooved, or gouged by a knife is the preferred criteria

A few empirical and quantitative field techniques which are quick, easy, and inexpensive are available to provide strength estimates. Quantitative strength estimates can be obtained from the point load test. A lightweight and portable testing device is used to break a piece of core (with a minimum length at least 1.5 times the diameter) between two loading points. If a new fracture does not run from one loading point to the other upon completion of the test, or if the points sink into the rock surface causing excessive deformation or crushing, the test should not be recorded. Raw data are given with the reduced data (equations to empirically convert load data to compressive strengths are usually supplied with the equipment). The Schmidt (*L*) hammer may also be used for estimating rock strengths; refer to Field Index Tests in chapter 5. Each of these tests can be used to calibrate the manual index (empirical) properties described in table 4-6, and a range of compressive strengths can be assigned. Depending on the scope of the study and structure being considered, laboratory testing may be required and used to confirm the field test data.

Discontinuities.—Describe all discontinuities such as joints, fractures, shear/faults, and shear/fault zones, and significant contacts. These descriptions should include all observable characteristics such as orientation, spacing, continuity, openness, surface conditions, and fillings. Appropriate terminology, descriptive criteria and descriptors, and examples pertaining to discontinuities are presented in chapter 5.

Contacts.—Contacts between various rock units or rock/soil units must be described. In addition to providing a geologic classification, describe the engineering characteristics such as the planarity or irregularity and other descriptors used for discontinuities.

Descriptors applicable to the geologic classification of contacts are:

- Conformable
- Unconformable
- Welded—contact between two lithologic units, one of which is igneous, that has not been disrupted tectonically
- Concordant (intrusive rocks)
- Discordant (intrusive rocks)

Descriptors pertinent to engineering classification of contacts are:

- Jointed—contact not welded, cemented, or healed—a fracture
- Intact
- Healed (by secondary process)
- Sharp
- Gradational
- Sheared
- Altered (baked or mineralized)
- Solutioned

If jointed or sheared, additional discontinuity descriptors such as thickness of fillings, openness, moisture, and roughness, should be provided also (see discontinuity descriptors in chapter 5).

Permeability Data.—Permeability (hydraulic conductivity) is an important physical characteristic that must be described. Suggested methods for testing, terminology, and descriptors are available in the *Earth Manual* and *Ground Water Manual.* Numerical values for hydraulic conductivity (K) can be determined using any of several methods. These values may be shown on drill hole logs. For narrative discussions or summary descriptions, the numerical value and descriptors may be used. Descriptors to be used—such as low, moderate—are those shown on figure 4-7. Whether permeability is primary (through intact rock) or secondary (through fractures) should be indicated.

Example Descriptions

The examples which follow are in representative formats for describing bedrock in the physical conditions column of drill hole logs and on a legend, explanation, and notes drawing.

Core Log Narrative

Several examples of descriptions for core logs are presented. These examples illustrate format and the use of the lithologic descriptors but do not include a description of discontinuities.

Log with Alphanumeric Descriptors and English Units.—

> . . . 12.6 to 103.6: Amphibolite Schist (JKam). Fine-grained (0.5 to 1 mm); subschistose to massive; greenish-black (5G 2/1) with numerous blebs and stringers of white calcite to 0.02 ft thick with solution pits and vugs to 0.03 ft, mostly 0.01 ft, aligned subparallel to foliation; very thinly foliated, foliation dips 65° to 85°, steepening with depth. Moderately to slightly weathered (W4), iron oxide staining on all discontinuities. Hard (H3), can be scratched with knife with heavy pressure, core breaks parallel to foliation with heavy hammer blow. Slightly fractured (FD3),. . ..

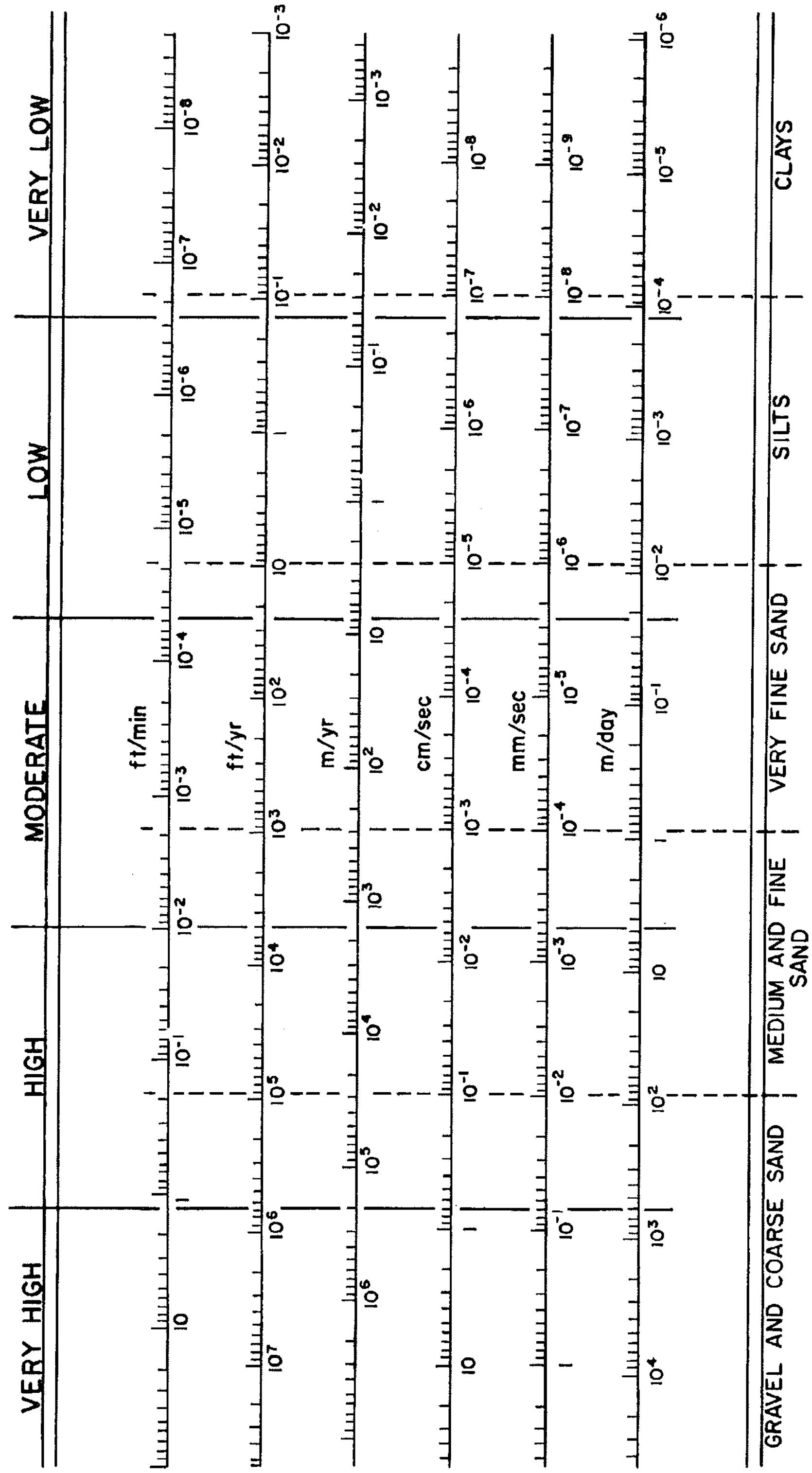

Figure 4-7.—Permeability conversion chart.

Log with Alphanumeric Descriptors Using Metric Units.—

103.60 to 183.22: Sandstone (TU_{sa}). Ferruginous quartzose sandstone. Medium-grained (0.25 to 0.5 mm), well sorted, subrounded to rounded quartz grains are well cemented by silica; hematite occurs as minor cement agent and as thin coating on grains. Moderate reddish-brown (10R 6/6). Moderately bedded, beds 250 to 310 mm thick, bedding dips 15° to 29°, averages 18°. Slightly weathered. Hard, cannot be scratched with knife, core breaks with heavy hammer blow across bedding and through grains. Moderately fractured. Core recovered. . ..

172.41-176.30: Claystone (TU_{c2}). Calcareous montmorillonitic clay with 20 percent subangular, fine sand-size quartz fragments. Strong reaction with hydrochloric acid (HCl), grayish pink (5R 8/2). Moderately to rapidly slaking when dropped in water. Very thinly bedded to laminated with bed thickness from 8 to 20 mm. Very intensely weathered. Very soft, can be gouged with fingernail, friable, core breaks with manual pressure, smaller fragments can be crushed with fingers. . . Upper contact is parallel to bedding, conformable, gradational, and intact; lower contact is unconformable, sharp and jointed but tight; dips 35° . . ..

Legend

The example which follows could be typical of a rock unit description on a general legend, explanation, and note drawing. The object is to describe as many physical properties as possible which apply to the entire rock unit at the site. If individual subunits can be differentiated, they could be assigned corresponding symbols and described below the undifferentiated description. Those characteristics in the subunits which are similar or are included in the undifferentiated unit do not need to be repeated for each subunit.

Amphibolite Schist - Undifferentiated.—Mineralogy variable but generally consists of greater than 30 percent amphibole. Contains varying percentages of feldspar, quartz, and epidote in numerous, thin, white and light green (5G 7/4), discontinuous stringers and blebs. Texture ranges from fine grained and schistose to medium grained and subschistose. Overall, color ranges from greenish black (5G 2/1) to olive black (5Y 2/1). Thinly foliated; foliation dips steeply 75° to 85° NE. Weathering is variable but generally moderately weathered to depths of 75 ft, slightly weathered to 120 ft, and fresh below. Where oxidized, moderate reddish-brown (10R 4/6), frequently with dendritic patterns of oxides on discontinuities. Hard, fresh rock can be scratched slightly with heavy knife pressure; fresh N-size core breaks along foliation with moderate to heavy hammer blow. Foliation joints are variably spaced and discontinuous, spaced more closely where weathered. Joint sets are prominent but discontinuous. (Joint sets are identified in the specifications paragraphs). Commonly altered 0.1 to 6 ft along contacts of dikes and larger shears with epidote and quartz ("altered amphibolite" on logs of exploration). When altered, harder than amphibolite. Based on drill hole permeability testing, hydraulic conductivity is very low to low, with values ranging from 0.09 to 130 feet per year (ft/yr) averages 1.5 ft/yr in slightly weathered and fresh rock.

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APPENDIX B

FIELD FORMS

BOREHOLE LOGGING FORM

BORING LOCATION	Project: ________ Project No: ________ Date Drilled: ________ Date Completed: ________ Logged By: ________	Boring ID: ________ Northing: ________ Easting: ________
	Water Elevation (ft.): ________ Date Measured: ________	Ground Surface Elevation (ft.): ________ Datum: ________
	Inclination: ________ Azimuth: ________	
	Total Depth (ft.): ________ Diameter (in.) ________	Drilling Contractor: ________ Drilling Method: ________
	Abandonment Information: ________	

DEPTH (FEET)	SOIL GRAIN SIZE % GRAVEL	% SAND	% FINES	SS BLOWS (6 in)	SAMPLE TYPE *	SAMPLE RECOVERY	USCS/USBR/ASTM CLASSIFICATION	GRAPHIC LOG	DESCRIPTION (Soil or rock unit name; color; size and angularity composition of each component or plasticity; density; moisture content; contacts; bedding; additional facts)	ELEVATION (FEET)

* **C** California Split Spoon Sampler (2.5" I.D.)
S Standard penetration test sampler
c Cuttings

▼ Elevation of ground water
ss Split spoon
o RC cuttings

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Project ______________________ Project No ________________

Boring I.D. ___________________

DEPTH (FEET)	SOIL GRAIN SIZE % GRAVEL	% SAND	% FINES	SS BLOWS (6 in)	SAMPLE TYPE *	SAMPLE RECOVERY	USCS/USBR/ASTM CLASSIFICATION	GRAPHIC LOG	DESCRIPTION (Soil or rock unit name; color; size and angularity composition of each component or plasticity; density; moisture content; contacts; bedding; additional facts)	ELEVATION (FEET)

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TRENCH TEST PIT LOG FORM

Page _____ of _____

Project ______________________ Project Number ______________________

Sample Location ______________________ Trench Number ______________________ Date ______________

Coordinates: Inside Stake ______________________ Outside Stake ______________________

Native/Fill Stake ______________________

Logged By ______________________

TRENCH PROFILE

Depth in Feet

Feet

Subsurface description and filed USCS Classifications
(USCS name, color, size and angularity or plasticity, density, moisture content, additional facts and debris encountered)

____

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____

____

Begin Trench ______________ Finish Trench ______________ Trenching Contractor ______________

Total Depth ______________ Total Length ______________

MAJOR DIVISIONS			GRAPH SYMBOL	LETTER SYMBOL	LETTER DESCRIPTIONS
COARSE GRAINED SOILS MORE THAN 50% OF MATERIAL IS LARGER THAN NO. 200 SIEVE SIZE	GRAVEL AND GRAVELLY SOILS MORE THAN 60% OF COARSE FRACTION RETAINED ON NO. 4 SIEVE	CLEAN GRAVELS (LITTLE OR NO FINES)		GW	Well-graded gravels, gravel-sand mixtures, little or no fines
				GP	Poorly graded gravels, gravel-sand mixtures, little or no fines
		GRAVELS WITH FINES (APPRECIABLE AMOUNT OF FINES)		GM	Silty gravels, gravel-sand-silt mixtures
				GC	Clayey gravels, gravel-sand-clay mixtures
	SAND AND SANDY SOILS MORE THAN 50% OF COARSE FRACTION PASSING NO. 4 SIEVE	CLEAN SAND (LITTLE OR NO FINES)		SW	Well-graded sands, gravelly sands, little or no fines
				SP	Poorly graded sands, gravelly sands, little or no fines
		SANDS WITH FINES (APPRECIABLE AMOUNT OF FINES)		SM	Silty sands, sand-silt mixtures
				SC	Clayey sands, sand-clay mixtures
FINE GRAINED SOILS MORE THAN 50% OF MATERIAL IS SMALLER THAN NO. 200 SIEVE SIZE	SILTS AND CLAYS	LIQUID LIMIT LESS THAN 50		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity
				CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
				OL	Organic silts and organic silty clays of low plasticity
	SILTS AND CLAYS	LIQUID LIMIT GREATER THAN 50		MH	Inorganic silts, micaceous or diatomaceous fine sand or silty soils
				CH	Inorganic clays of high plasticity, fat clays
				OH	Organic clays of medium to high plasticity, organic silts
HIGHLY ORGANIC SOILS				PT	Peat, humus, swamp soils with high organic contents

Note: *For coarse soils: gravels and sands with 5 to 12 percent fines require dual symbols . Soils 15 percent sand or gravel, add with sand or with gravel. For fine grained soils: If 15 to 29 percent sand or gravel add with sand or with gravel or name. If 30 percent sand or gravel add sandy or gravelly to group name.*

UNIFIED SOIL CLASSIFICATION SYSTEM

Adopted by Corps of Engineers
and Bureau of Reclamation, January, 1952,
in collaboration with A. Casagrande, PhD.

SAMPLE LOG FORM

Sample I.D. ______________________ Sample Location I.D. ______________________

Mine Location ______________________ Sample Depth ______________________

Sample Collection Date ______________________

Sample Collection Time ______________________

Sample Collected by ______________________

Weather Conditions ______________________

Location Coordinates ______________________

Field USBR/USCS Descriptions ______________________

Major Divisions: ☐ OH ☐ CH ☐ MH ☐ OH ☐ CL ☐ ML ☐ SC Rock Unit(s) ____________

☐ SM ☐ SP ☐ SW ☐ GC ☐ GM ☐ GP ☐ GW

Qualifiers: ☐ Trace ☐ Minor ☐ Some; sand size ____________ ☐ Fine ☐ Medium ☐ Coarse

Moisture: ☐ Dry ☐ Moist ☐ Wet

Munsell Color ______________________

SAMPLE CONTAINER	PRESERVATIVE	ANALYTE	LAB VIAL WEIGHT (+ .01 G.)	EMPTY FIELD VIAL WEIGHT (+ .01 G.)	FILLED FIELD VIAL WEIGHT (+ .01 G.)

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